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Argonne National Laboratory

PHYSICS DIVISION SUMMARY REPORT

Annual Review

1 April 1964 — 31 March 1965

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ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60440

PHYSICS DIVISION SUMMARY REPORT

Annual Review
1 April 1964—31 March 1965

Lowell M. Bollinger, Division Director

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FOREWORD

This issue of the ANL Physics Division Summary Report presents a comprehensive picture of the work of the Division in the year ending in the spring of 1965. Instead of the usual small selection of relatively full accounts of individual researches reported at the random times at which they become available, this issue offers a complete and systematic overview of what is going on. Much of what is indicated briefly here has been described more fully in earlier issues of the Summary; most of the rest will appear in forthcoming issues.

In addition, the papers published in the 1-year period from 1 April 1964 through 31 March 1965 are listed immediately after the reports on the research. This list accounts for much the same effort but from a different point of view.

Still another picture of the relative emphases on the different programs of the Division is supplied by the roster of personnel, in which the staff members are grouped by program. (It must be understood, however, that staff members frequently do part of their work in another program.) This roster forms the last section of the report.

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I. EXPERIMENTAL NUCLEAR PHYSICS

INTRODUCTION

The over-all purpose of the program continues to be, as in the past, to obtain a much more complete understanding of the atomic nucleus. Consequently, most of the program consists of experimental and theoretical studies of the energies, quantum numbers, and lifetimes of nuclear energy levels and investigations of the mechanisms by which simple nuclear projectiles interact with nuclear targets. Experimenters and theorists work closely together so that new results in one area may suggest new approaches in another. An effort is made to stress work that can be done more advantageously at Argonne than elsewhere because of the special facilities available here. In view of the history and tradition of the Laboratory, it is natural that considerable emphasis is placed on studies of interactions between nuclei and neutrons; but this is balanced by a well diversified program of other nuclear investigations.

With a few exceptions, the program in experimental nuclear physics is most easily outlined by subdividing the work into various categories for which a major piece of equipment or an important experimental technique is the unifying factor. The categories formed in this way are the following:

(1) Studies of the neutron and of neutron-induced reactions at the reactor CP-5.

(2) Neutron and charged-particle-induced reactions at the 4.5-MeV Van de Graaff.

(3) Charged-particle reactions at the tandem Van de Graaff accelerator.

(4) Charged-particle reactions at the 60-in. cyclotron.

(5) Various other nuclear experiments, including the γ- and β-ray spectroscopy of radioactive sources.

Some physicists restrict their efforts to the use of a single machine or technique, whereas others investigate related problems with several systems of apparatus.

A. RESEARCH AT THE REACTORS CP-5 AND JUGGERNAUT

The program of the Physics Division at the reactor CP-5 is devoted entirely to nuclear physics. The experiments fall into three broad categories—experiments on the fundamental properties of the neutron, studies of neutron cross sections, and a variety of experiments with neutron-capture gamma rays.

The first category includes a measurement of the neutron-electron interaction and studies of the decay of polarized neutrons.

Neutron cross sections are measured by the time-of-flight method with a fast chopper. Recently this system has been used principally to measure total cross sections and to study the gamma-ray spectra that result from the capture of neutrons in resonances.

The largest area of investigation is concerned with the study of nuclear structure by various measurements on the thermal-neutron-capture gamma rays. Most of the experiments of this kind have been revolutionized during the past year by the development of the lithium-drifted germanium-diode gamma-ray spectrometer. As a result of the excellent resolution and relatively high efficiency of this new spectrometer, the data required to construct refined nuclear level diagrams and decay schemes can now be obtained with ease.

1. INSTRUMENTATION FOR MEASUREMENTS OF THE SYMMETRY PROPERTIES OF NEUTRON DECAY

M. T. Burgy and G. R. Ringo

The importance of these measurements to the theory of weak interactions calls for substantially more accurate measurements than those done previously. To reduce statistical uncertainty by raising the neutron beam intensity, the polarizing mirror is being redesigned. One design has been eliminated because of difficulties in fabricating the special component mirrors. Other designs are under consideration. Another goal is to reduce the uncertainty in the measurement of neutron polarization to less than 2%. There are two principal difficulties. (a) The large range of neutron wavelengths in the beam from the polarizer raises the possibility that certain parts of the spectrum are unduly weighted at the expense of other parts in the polarization measurement. To greatly reduce this possible error, a pair of mirrors (magnetized in the same magnet) is being used in the analyzer mirror. (b) The other difficulty arises from small-angle multiple scattering in the steel depolarizing foil used in the measurement. In a polarization measurement, the effect of this scattering is similar to that of the accompanying depolarization of the beam. The desired reliability appears to have been attained by compensating for the scattering so that the depolarization effect can be isolated, the method being to use thin sheets of graphite which produce small-angle scattering of the neutrons but do not depolarize them.

2. ELECTRON-NEUTRON INTERACTION

V. Krohn and G. R. Ringo

The objective of this program is to achieve a precise measurement of the low-energy electron-neutron interaction by studying the fore-and-aft asymmetry in the scattering of thermal neutrons by noble gases.[1]

For some time the electron-neutron interaction has been believed to be about equal to the Foldy term[2] which is -4080 eV in terms of the effective potential acting over a sphere having a radius equal to

---

[1] E. Fermi and L. Marshall, Phys. Rev. 72, 1139 (1947).

[2] L. Foldy, Rev. Mod. Phys. 30, 471 (1958); D. J. Hughes, J. A. Harvey, M. D. Goldberg, and M. J. Stafne, Phys. Rev. 90, 497 (1953); E. Melkonian, B. M. Rustad, and W. W. Havens, Phys. Rev. 114, 1571 (1959).

the classical radius of the electron. However, the analysis of some of the recent electron-scattering data[3] seems to imply that the low-energy electron-neutron interaction should be much smaller than this (i.e., near zero).

Xenon, krypton, and argon were used as scattering gases for the measurement. The "effective" potential for the interaction was found to be -3760 ± 520 eV from the argon data, -3520 ± 210 eV from the krypton, and -3320 ± 190 eV from the xenon. The final value is -3440 ± 160 eV. In the usual notation for nucleon form factors, this result implies that $(dG_{EN}/dq^2)_{q=0} = +0.0178 \pm 0.0009\ F^2$. The program is continuing.

[3] J. R. Dunning, Jr., K. W. Chen, A. A. Cone, G. Hartwig, N. F. Ramsey, J. K. Walker, and Richard Wilson, Phys. Rev. Letters 13, 631 (1964).

3. NEUTRON RESONANCES

L. M. Bollinger, R. E. Coté, H. E. Jackson, J. P. Marion, and G. E. Thomas

Since the last report, the new 4096-channel time analyzer has been installed at CP-5 and modifications to the damping device in the chopper have resulted in reproducibility to about 0.001 in. in the position of the rotor at a particular speed. The latter is important because the spectrum of neutrons that arrive at the detector depends on the relative position of the rotor with respect to the collimator. More details of the new time analyzer are given below.

a. Resonance Structure of Th^{230}

The program to study the neutron resonances of the heavy nuclides of low abundance has been continued through the study of the transmission of samples of Th^{230} (prepared by H. Diamond and J. E. Gindler of the Argonne Chemistry Division). The resonance parameters of some twenty resonances below 300 eV were determined. The measured radiation width of 0.024 ± 0.002 eV agrees with the value computed on the basis of the semiempirical relation of Cameron.[1] The value of the strength function $\overline{\Gamma}_n^0/D = \left(1.6^{+0.6}_{-0.4}\right) \times 10^{-4}$ is considerably larger than for neighboring nuclides.[2] However, this very probably does not represent a real difference, but rather a statistical deviation that can be expected from results based on few resonances.

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[1] A. G. W. Cameron, Can. J. Phys. 35, 666 (1957).

[2] R. E. Coté, R. F. Barnes, and H. Diamond, Phys. Rev. 134, B1281 (1964).

b. p-Wave Resonances at Very Low Energy

Two steps have been taken to increase our ability to detect and resolve small p-wave resonances. Samples are cooled to liquid-nitrogen temperature to lessen the Doppler broadening and increase the depth of transmission dips from these small resonances. In addition, the new 4096-channel analyzer (which has a very large storage capacity per channel, short dead time, and flexible channel-width selection) has been used.

With the new system, the transmission of a thick, exceptionally pure sample of Th^{232} was measured in a re-examination of the p-wave resonances at energies less than 100 eV. The previously reported[1] resonances were observed with improved statistical and instrumental accuracy but no new resonances were detected.

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[1] L. M. Bollinger and G. E. Thomas, Phys. Letters 8, 45 (1964).

A similar study[2] of the transmission of a thick sample of U^{238} revealed numerous tiny transmission dips at energies less than 100 eV. A quantitative examination of the areas of these dips shows that they almost surely result from p-wave interactions. Curve fitting of the one at lowest energy (4.4 eV) yields a radiation width $\Gamma_\gamma = 0.020 \pm 0.010$ eV, a value that is equal within errors to the width for s-wave resonances.

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[2] G. E. Thomas and L. M. Bollinger, Bull. Am. Phys. Soc. 10, 513 (1964).

c. The Odd-A Isotopes of Molybdenum

The new time analyzer has been used in a study of the resonance structure of Mo^{95} and Mo^{97}. A sample of natural molybdenum was studied under identical conditions so that the more complicated resonance structure could more easily be understood. Studies of the transmission of these samples below 1 keV revealed 33 resonances in Mo^{95} and 50 in Mo^{97}. Measurements of the capture γ-ray spectra were also made with the samples of Mo^{95} and Mo^{97} and it is hoped that these will be useful in establishing the parity of some of the weaker resonances, some of which may be attributable to p-wave neutrons.

d. The New 4096-Channel Time Analyzer[1]

In order to meet the needs arising from the continual improvement in the intensity and precision of the Argonne Fast Chopper and the associated detection system, the new time analyzer mentioned above has been constructed by C. C. Rockwood of the Argonne Electronics Division and incorporated into the fast-chopper time-of-flight

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[1] C. C. Rockwood, Rev. Sci. Instr. (in press).

spectrometer at the reactor CP-5. With this system, extremely large volumes of experimental data can be accumulated over a broad range of neutron flight times with a high degree of flexibility. As indicated earlier, the analyzer currently is being exploited in measurements of total neutron cross sections of very high statistical accuracy—an order of magnitude better than that of earlier measurements.

Important characteristics of the analyzer include: a total of 4096 channels, control of the channel widths of individual blocks of 256 channels over a range from $\frac{1}{8}$ μsec to 128 μsec, a memory capacity of 262 144 counts per channel, a constant dead time of 5 μsec per event, provision for splitting the memory into two blocks of 2048 channels, and a "verify" mode of operation which makes possible the detection of errors in the readout by comparing it rapidly with the content of the memory. The large number of channels permits simultaneous accumulation of data over almost the full range of neutron energies, especially since the "accordion feature" of the channel-width control enables the experimenter to select narrow channels in the region of prime interest to obtain maximum time resolution, while other regions are scanned with wider channels. A high memory capacity per channel provides for the acquisition of very accurate time-of-flight spectra, and is sufficient to permit the observation of transmission dips as small as a few tenths of a percent in a single run. The correction of the experimental spectrum for dead-time effects is kept relatively small by the short dead time of the analyzer, in spite of the high instantaneous counting rates obtained with the new detection system.

e. A Boron-Loaded Scintillator with Very Low γ-Ray Sensitivity[1]

A new liquid scintillator for the detection of slow neutrons has been developed; it has very high neutron efficiency but an extremely

[1] H. E. Jackson and G. E. Thomas, Rev. Sci. Instr. (April 1965).

TABLE I. Characteristics of four representative scintillators. Each solution contains about 45 g/liter of boron. Abbreviations of the components of the scintillators: PBD = 2-phenyl-5-(4-biphenylyl)-1, 3, 4-oxadiazole; IPBP = mono-isopropyl biphenyl; EMB = enriched methyl borate (0.95 B^{10}); POPOP = 1, 4-di-[2-(5-phenyloxazolyl)]-benzene; αNPO = 2-(1-napthyl)-5-phenyloxazole; DPA = 9, 10-diphenylanthracene.

Solution	Composition by weight	Relative pulse height (neutrons)	Reduction factor ($Eff_{neutron}$ = 95%)
(a)	PBD (0.4%) + IPBP (49.3%) + EMB (49.3%) + POPOP (20 mg/liter)	0.58	1.2
(b)	PBD (1.2%) + Napthalene (21.7%) + EMB (46.5%) + IPBP (30.6%)	0.83	2
(c)	αNPO (1.2%) + Napthalene (21.7%) + EMB (46.5%) + IPBP (30.6%)	0.84	5
(d)	DPA (1.2%) + Napthalene (21.7%) + EMB (46.5%) + IPBP (30.6%)	1.00	500

low γ-ray sensitivity. This detector offers a solution to one of the most persistent experimental problems of neutron spectroscopy, namely the observation of resonance and thermal neutrons in the presence of a high γ-ray background. The reduction in γ-ray sensitivity is accomplished by distinguishing neutron events from γ-ray events on the basis of differences in the shapes of pulses produced by the scintillator; the final design of the counter resulted from an exhaustive study of the pulse-shape characteristics of a large number of solutions. The maximum factor by which the γ-ray sensitivity can be reduced without a significant decrease in neutron-counting efficiency was determined for a large group of liquids (Table I). With the best of these liquids, neutron events can be almost completely separated from γ-ray events. A large-area bank of these detectors is now being constructed for use with the Argonne fast chopper in transmission measurements made over a 120-meter flight path. In the past, the effectiveness of the 120-m detection station has been severely limited by the high background relative to flux of resonance neutrons. Recent tests indicate that the background is effectively suppressed by use of pulse-shape discrimination with the new scintillator.

4. THERMAL-NEUTRON CAPTURE GAMMA-RAY STUDIES

H. H. Bolotin

This experimental program seeks to provide information concerning the low-lying states of odd-odd nuclei and the transitions between them by observation of gamma rays following slow-neutron capture in selected odd-Z/even-N target nuclei. The multiplicity of gamma rays from the thermal-neutron capture state to low-lying levels permits the population of levels whose spins and parities may be significantly different from that of the initial capture state. Because of this feature, studies of neutron-capture gamma rays may reveal some levels that are not populated in (d,p), (d,t), and other interactions (in which they are inhibited by angular momentum or other restrictions). Therefore, the data from these neutron-capture studies provide a valuable complement to the information obtained in other ways.

These investigations were conducted at the Argonne "Juggernaut" reactor, which operates at a thermal power level of 200 kW. With the aid of a versatile 8-fold digitally gated coincidence system used in conjunction with an 800-channel pulse-height analyzer, both coincidence and singles spectra are obtained. Scintillation detectors alone were used in the earlier phases of the study. But more recently, Li-drifted Ge gamma-ray detectors have also been used to provide the high resolution (FWHM = 3.2 keV at 1.33 MeV) necessitated by the high density of low-lying states in odd-odd nuclei.

a. Low-Lying Excited States of Sc^{46} Populated in the Reaction $Sc^{45}(n,\gamma)Sc^{46}$

In these concluded investigations,[1] the thermal-neutron capture reactions $Sc^{45}(n,\gamma)Sc^{46}$ was utilized to populate the low-lying states in Sc^{46} by means of gamma-ray cascades from the compound-nucleus capture level. Scintillation singles and coincidence gamma-ray spectroscopy techniques were used to study the gamma-ray decay characteristics of the levels observed. A rather complete set of data has been obtained for transitions between levels at excitation energies up to 0.675 MeV. Levels at 0.142, 0.225, 0.289, 0.445, 0.585, and 0.675 MeV have been inferred, and the decay characteristics of each

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[1] H. H. Bolotin, Phys. Rev. 138, B795 (1965).

of these states have been determined. In addition, many levels up to an excitation energy of 3.62 MeV have been observed and the principal gamma-ray decay modes of these states have been described (Fig. 1).

Conventional and time-to-pulse-height delayed-coincidence techniques were employed to establish the "prompt" ($t_{1/2} \lesssim 2 \times 10^{-9}$ sec) lifetimes of the states at 0.225, 0.289, 0.445, 0.585, and 0.675 MeV. The isomeric character ($t_{1/2}$ = 20 sec) of the state at 0.142 MeV has been confirmed. A complete decay scheme for states up to an excitation energy of 0.675 MeV is proposed, and the observed characteristics of these levels are compared with previous (d, p) stripping studies and recent theoretical calculations.

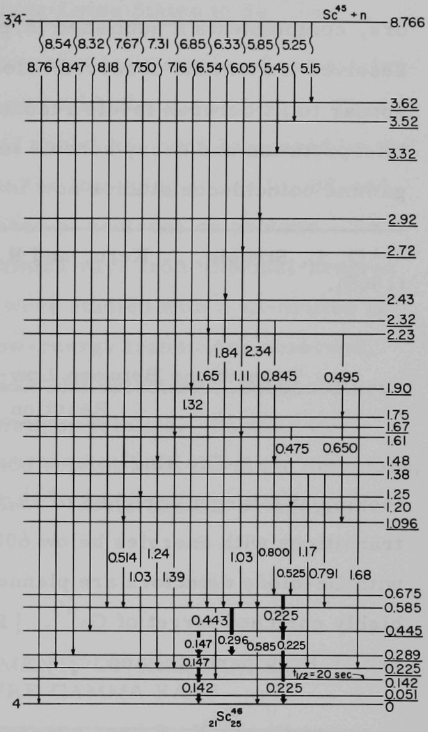


Fig. 1. Proposed decay scheme for levels up to an excitation energy of 3.62 MeV. The underlined excitation energies denote those states observed in previously reported (d, p) reaction studies.

b. Low-Lying Ho^{166} States from $Ho^{165}(n,\gamma)Ho^{166}$

Experimental studies of the low-lying levels of odd-odd deformed nuclei are of interest because of the information they can provide about the influence that interactions between the odd nucleons have on the characteristics of the low-lying states in the presence of collective motion. The present study, carried out with Ge-diode detectors, complements a published (d, p) investigation.[1] Many of the 30 resolved transitions observed below 0.511 MeV in the singles spectrum appear to fit between levels reported in the (d, p) work; but a definitive interpretation and decay scheme must await analysis of the gamma-gamma coincidence studies now in progress.

[1] G. L. Struble, J. Kern, and R. K. Sheline, Phys. Rev. 137, B772 (1965).

c. Transitions Between Low-Lying Ga^{72} States Populated in the Reaction $Ga^{71}(n, \gamma)Ga^{72}$

The singles spectrum, obtained from a Ge-diode detector looking at a target enriched to 99.8% in Ga^{71}, revealed more than 40 transitions with energies below 600 keV (Fig. 2). Coincidence studies with Ge-diode detectors are planned, as are similar studies with a highly enriched target of Ga^{69}. [For other work on Ga isotopes, see Sec. I. F. 2, parts (b) and (c).]

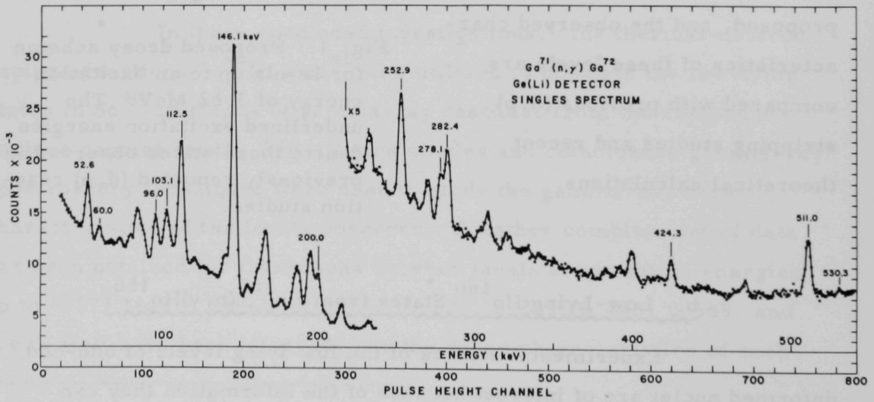


Fig. 2. Typical low-energy gamma-ray spectra in Ga^{72} following thermal-neutron capture in Ga^{71}.

d. Transitions Between Low-Lying States in Sb^{122}

Recent theoretical treatments have employed the pairing-interaction approach to the short-range residual nuclear force. The attempt to apply this theory to odd-odd nuclei has been hampered by the lack of sufficient experimental data on the low-lying states in odd-odd nuclei that have close to a magic number of neutrons or protons. To supply such information, the Sb^{122} gamma rays from thermal-neutron capture in Sb^{121} (enriched to 98.4%) were studied with a Li-drifted Ge detector. Of the several scores of low-energy transitions observed, only a few had previously been seen with NaI detectors. Several lines were found to be closely-spaced doublets or triplets. Further work will include gamma-gamma coincidence studies with Ge-diode detectors. A similar investigation of low-lying Sb^{124} levels excited by neutron capture in enriched Sb^{123} is planned.

5. PRECISION MEASUREMENTS OF HIGH-ENERGY NEUTRON-CAPTURE GAMMA RAYS

H. E. Jackson, Arthur Namenson, and R. K. Smither

A new facility under development at the CP-5 research reactor is designed for precision measurements of high-energy γ rays resulting from thermal-neutron capture in targets of separated isotopes. Until recently this type of measurement was made with magnetic spectrometers. Only targets of natural isotopic composition could be used since the low efficiency characteristic of such instruments permitted measurements only with samples of relatively large mass. However, making the same type of measurement with the newly developed lithium-drifted germanium detectors instead of with magnetic spectrometers leads to better energy resolution and a detection efficiency several orders of magnitude higher. Thus for the first time measurements are feasible with sufficiently small samples to allow the use of separated isotopes. With such targets isotopic assignments of capture γ rays can be made unambiguously, and in many cases transitions that are too weak to be observed in the spectrum from a natural sample can be observed.

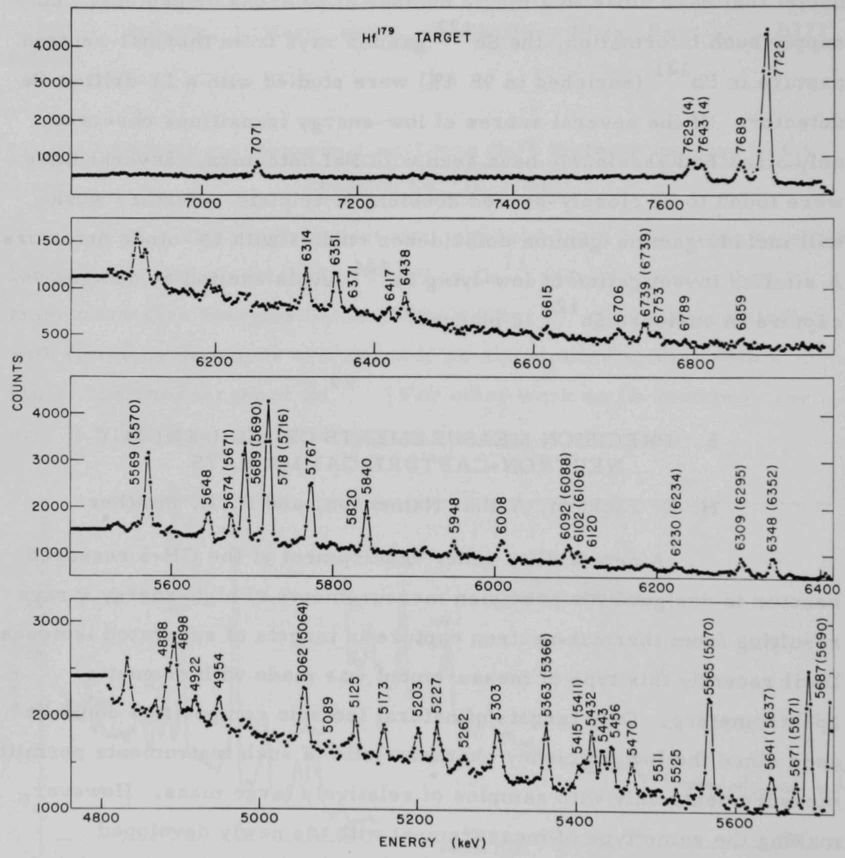


Fig. 3. Neutron-capture spectrum from a target of Hf^{179} as observed in a Ge(Li) detector. The energy resolution width is 7 keV at 7 MeV.

A beam tube which passes through the core of CP-5 is currently being modified to permit the irradiation of these targets with the highest attainable neutron fluxes, but under conditions of minimum background. The capture spectra are observed in a Ge(Li) detector with an energy resolution width of about 7 keV at 7 MeV. A typical example is shown in Fig. 3. To date samples of natural hafnium, Hf^{177}, and Hf^{179} have been investigated. Accurate values of several neutron binding energies were determined from these measurements (Table II). The data also have been used to observe new states in the level schemes of Hf^{178}, Hf^{179}, and Hf^{180}. If the high-energy lines in the capture spectra are interpreted as primary transitions, the results establish the existence of 15 new states in Hf^{178} within 2 MeV of the ground state. In view of the initial success, a program of systematic measurements of a large number of targets is planned.

TABLE II. Comparison between previous values of the binding energies and the values determined from the present measurements.

Nuclide	Neutron binding energy (keV)	
	Old value	New value
Hf^{178}	7619 ± 5	7623 ± 3
Hf^{179}	6098 ± 14	6098 ± 4
Hf^{180}	7360 ± 50	7383 ± 4
Hf^{181}	~ 5800	5693 ± 3

6. STUDY OF RADIATION WIDTHS OF LOW-ENERGY NUCLEAR STATES BY RESONANCE SCATTERING OF NEUTRON-CAPTURE GAMMA RAYS

H. S. Hans, G. E. Thomas, and L. M. Bollinger

The radiation widths of low-energy nuclear states have been measured by a new technique based on the resonance scattering of thermal-neutron-capture gamma rays. The basic idea of the technique is similar to that of a resonance-scattering experiment in which the nuclear recoil provided by emission of a beta ray from radioactive decay is used to compensate for the recoil energy loss of a subsequent radiative transition to the ground state. In our measurement, the recoil energy loss associated with a transition to the ground state is compensated by the recoil from preceding transitions in the neutron-capture gamma-ray cascade. If the recoil-broadened gamma-ray line formed in this way is broad enough to overlap the energy of the emitting state, one may observe resonance scattering by a target containing the product nucleus formed by neutron capture. From this scattering the partial radiation width of the state may be deduced by an absorption measurement. Since resonance scattering of this kind can occur for states up to half of the neutron binding energy, the expected advantage of the new technique is that it will be useful at higher energies than are other methods of measuring radiation widths.

In our experiment, the target with neutron number N is placed near the core of the reactor CP-5. The capture gamma rays then are resonantly scattered from the (N + 1) isotope of the same element and are detected in a NaI(Tl) detector. The radiation widths are measured by the self-absorption method. Resonances have been observed and studied at 1.84 and 3.5 MeV in Sr^{88}; 2.14, 4.46, and 5.03 MeV in B^{11}; and 3.35, 4.57, and 5.21 MeV in Se.

The results obtained to date indicate that the resonance scattering of neutron-capture gamma rays is a useful tool for the measurement of radiation widths of a limited class of targets.

7. HIGH-RESOLUTION STUDIES OF THERMAL-NEUTRON-CAPTURE GAMMA-RAY SPECTRA

R. K. Smither, A. P. Magruder, and A. I. Namenson

a. Measurements with the Bent-Crystal Spectrometer

Precision energy and intensity measurements on the neutron-capture gamma-ray spectra of $Sm^{152}(n,\gamma)Sm^{153}$, $Hf^{179}(n,\gamma)Hf^{180}$, and $Cd^{113}(n,\gamma)Cd^{114}$ were made with the 7.7-m bent-crystal spectrometer. The detailed gamma spectra (30 keV—2 MeV) obtained in these crystal diffraction experiments are being combined with the Ge-diode measurements of Jackson, Namenson, and Smither (Sec. I. A. 5) on the high-energy portion (2—10 MeV) of the neutron-capture gamma spectra to obtain the level schemes of Sm^{153}, Hf^{180}, and Cd^{114}. The work on Sm^{153} and Hf^{180} is new. The Cd^{114} experiments will modify and extend the level scheme of Cd^{114} based on previous crystal-spectrometer work done at Argonne (Smither). The emphasis of the new work is on higher precision (a factor of 2—3) and the elimination of systematic errors; it reflects the improvements of the spectrometer during the last few years.

This increased precision in the energy measurements is needed to facilitate the combining of the Ge-diode measurements with the crystal-spectrometer measurements and allows extension of the level scheme of Cd^{114} to 3 MeV excitation. A great many of the low-energy members of the capture spectrum can now be placed in the level

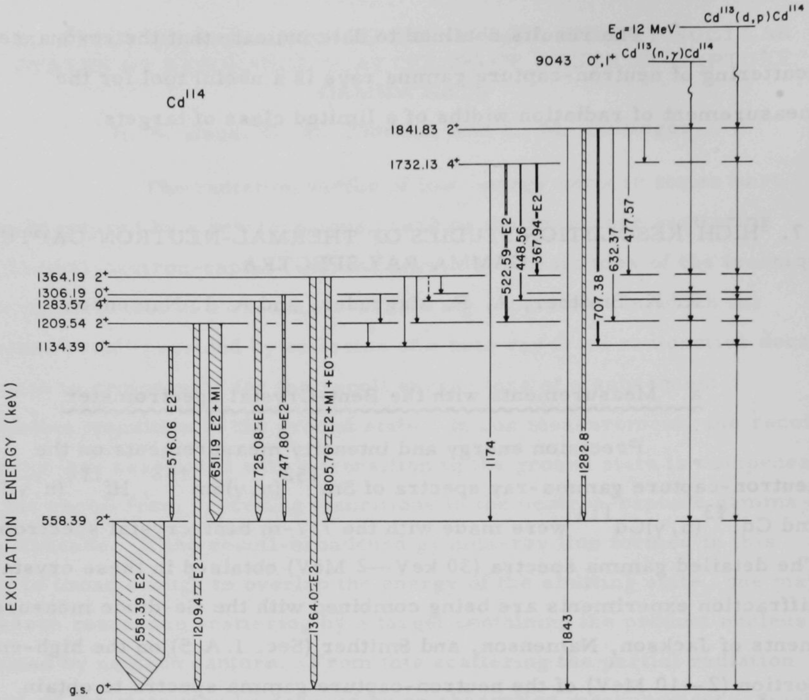


Fig. 4. Proposed level scheme of Cd^{114}. The excitation energies and proposed spin assignments are given to the left of each level. The energy and multipole assignment (when made) is given on each line. All energies are in keV. The high-energy Ge-diode data and the (d, p) data are presented on the right-hand side of the figure. Each arrowhead indicates an observed transition to the appropriate level.

scheme (Fig. 4). This results in a substantial increase in the detail of the level scheme for excitation energies between 1 and 3 MeV. Further information about the level scheme of Cd^{114} has been obtained from a series of $Cd^{113}(d,p)Cd^{114}$ experiments on the tandem Van de Graaff (Sec. I. C. 6. f). The combination of (d, p) work with the (n, γ) work is currently under way.

b. Modification of the Bent-Crystal Spectrometer

A number of important modifications of the bent-crystal spectrometer are currently under way.

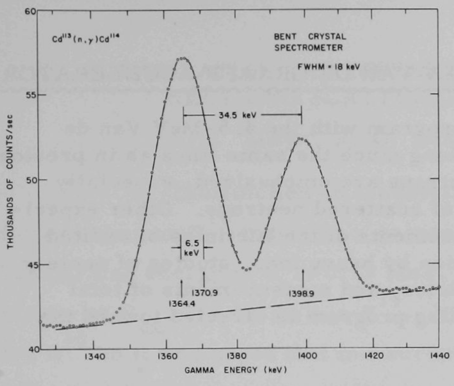
(i) A new source-handling system has been constructed and inserted in the reactor CP-5. This new system will allow the rapid insertion and removal of samples from the reactor. It will also allow highly radioactive samples to be stored and then reinserted at a later date without exposing personnel to radiation. This facility will greatly increase the flexibility of the crystal-spectrometer program and will allow short-term experiments with limited goals to be performed without excessive loss in running time. In preliminary tests of the new system, a 10% improvement was noted in the resolution of the spectrometer. This improvement is believed to be due to the ease with which the source in the reactor can be aligned with the new system.

(ii) A Ge crystal measuring $3\frac{1}{2} \times 3 \times 0.16$ in. has been bent and was installed in the crystal spectrometer in early April 1965. The crystal spectrometer has been modified to allow the bent crystal being used by the spectrometer to be changed according to the experimental needs. The experimenter can now choose between three quartz crystals (measuring $12 \times 11 \times 0.080$ in., $12 \times 12 \times 0.160$ in., and $6 \times 4 \times 0.240$ in.) and two Ge crystals ($3\frac{1}{2} \times 3 \times 0.160$ in.). It is estimated that a crystal can be changed in less than 2 hr with no loss in precision in the measurements. This will allow the experimenter considerable freedom even in short experiments. The investigation of a 40-keV gamma ray with the thin (0.080-in.) quartz crystal could be followed by a measurement at 4 MeV with the thick (0.160-in.) Ge crystal with only a small loss in running time.

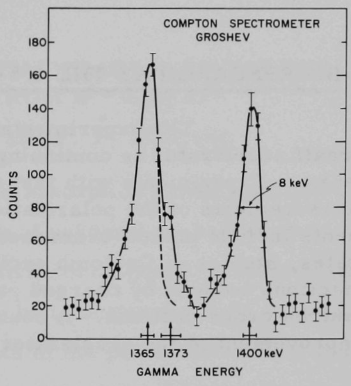
(iii) The construction of two new collimators for the crystal spectrometer is half completed. These two new collimators will extend the usable energy range of the crystal spectrometer both down in energy (from 40 keV to 15 keV) by removing material now obstructing the beam, and up in energy (from 2 MeV to 6 MeV) by improving the collimation. Insertion of these collimators is expected in late summer of 1965.

c. Ge-Diode Gamma-Ray Spectrometer Used with the Bent-Crystal Spectrometer

An experimental system consisting of the combination of a bent-crystal diffraction spectrometer and a Ge-diode detector has been developed for high-resolution studies of thermal-neutron-capture gamma rays. In the energy range $E_\gamma > 1$ MeV for which it is most useful, the system has several advantages over either the diffraction spectrometer or the Ge diode individually: (a) the monochromating action of the diffraction spectrometer eliminates most of the confusion and background associated with the complex line shape of the Ge diode, (b) the system combines the high resolution of the Ge diode with the precision of the diffraction spectrometer, and (c) the system may be used to make precision measurements of the energies of gamma rays from weak or short-lived radioactive sources. All of these advantages have been demonstrated experimentally. Measurements on the much-studied spectrum from the reaction $Cd^{113}(n,\gamma)Cd^{114}$ reveal previously unresolved lines that help establish a new energy-level diagram of Cd^{114}. Figure 5 is an example of the resolution of a close doublet in the Cd spectrum.

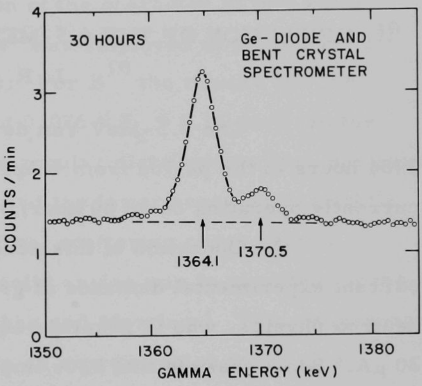


(a)



(b)

Fig. 5. The doublet at 1364 and 1371 keV in the gamma-ray spectrum from Cd^{114} formed by neutron capture in Cd^{113}.
(a) In the spectrum from the bent-crystal spectrometer, the only indication that the 1364-keV line is a doublet is the slight (5%) broadening of the peak. (b) In the high-resolution Compton-spectrometer work of Groshev, the second component shows as a small shoulder on the right-hand side of the main peak. (c) When the Ge diode and bent-crystal spectrometer are used in combination, the second component at 1370.5 keV is clearly resolved.



(c)

B. RESEARCH AT THE 4.5-MEV VAN DE GRAAFF ACCELERATOR

The experimental program with the 4.5-MeV Van de Graaff accelerator is continuing along much the same lines as in previous years. Experiments with fast neutrons are emphasized, especially measurements of the polarization of scattered neutrons. Other experiments include pulsed-beam measurements of the lifetimes of excited states, studies of Coulomb excitation by heavy ions, studies of nuclear reactions induced by charged particles, and measurements of total neutron cross sections. A continuing program is directed toward the improvement of the accelerator.

1. OPERATION OF THE 4.5-MEV VAN DE GRAAFF ACCELERATOR

J. R. Wallace

The 4.5-MeV Van de Graaff accelerator has operated 2984 hours in the period from 1 April 1964 to 31 March 1965. It is currently operating on an 80 hour/week schedule.

Operation of this accelerator has been geared to meet current experimental demands of groups of scientists interested in neutron physics, who in general require beam currents in excess of 20 μA. Some changes that have improved beam current and beam stability are: (1) additional bias rings in the beam-steering system and increased current capacity for its power supply, (2) new 30-kV power packs and large capacitors for the electrostatic analyzers, (3) additional vacuum pumps for the main system and for the beam-steering unit, and (4) a new power supply for the probe in the ion source.

Plans for next year include installation of an improved on-line link to the ASI-2100 computer and of a chilled-water system for cooling the machine, magnets, and vacuum pumps; and further work on the ion source, electrostatic analyzer, and belt drive are planned.

2. POLARIZATION AND DIFFERENTIAL CROSS SECTIONS FOR NEUTRONS SCATTERED FROM B^{10} AND B^{11}

A. J. Elwyn, R. O. Lane, and F. P. Mooring

Information on the total and absorption cross sections[1] for neutrons on B^{10} indicates a resonance of unknown character at a bombarding energy of $E_n \approx 0.25$ MeV, which corresponds to an excitation energy of $E_{ex} = 11.46$ MeV in B^{11}. Very little scattering data existed for B^{10} so it was hoped that measurements of the polarization $P(\theta)$ and differential cross section $\sigma(\theta)$ for neutron scattering might reveal new information leading to a determination of the character of this state. The experimental method used before[2] was employed to study both B^{10} (enriched to 97%) and B^{11} (natural B). For B^{10} the results for $P(\theta)$ were $0.0 \pm 4\%$ for the energy range of $0.075 \leqslant E_n \leqslant 0.50$ MeV; in the same energy range, the shapes of the angular distributions for unpolarized neutrons varied slowly from isotropic at the lower energies to slightly forward peaked at the highest. The total scattering cross section obtained by integrating $\sigma(\theta)$ over all solid angles was in excellent agreement with the recent results of Monahan and Mooring.[1] This nonresonant behavior for the scattering process in an energy region in which a resonance exists in the total and absorption cross sections indicates that the neutron width for the scattering process for this state is very much smaller than the widths for the other processes [probably the $B^{10}(n,\alpha)$ and possibly the $B^{10}(n,t)$ reactions] that are responsible for the resonance. Unfortunately this nonresonant behavior in the scattering also means that it is not possible under present circumstances to determine the character of the state from measurements of $P(\theta)$ and $\sigma(\theta)$.

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[1] F. P. Mooring and J. E. Monahan, Sec. I. B. 5.

[2] R. O. Lane, A. J. Elwyn, and A. Langsdorf, Jr., Phys. Rev. 133, B409 (1964).

For B^{11}, the results are consistent with earlier measurements of $P(\theta)$ and $\sigma(\theta)$. The well-known resonance at $E_n = 0.43$ MeV, corresponding to the state in B^{12} at $E_{ex} = 3.76$ MeV, has been assigned 2^+. It is formed via p waves either all in channel spin s = 1 or all in s = 2. When the present data are analyzed, it may be possible to resolve this uncertainty in the channel-spin dependence.

3. NEUTRON SCATTERING FROM NUCLEI NEAR A = 20

A. J. Elwyn, J. E. Monahan, R. O. Lane, and F. P. Mooring

As described in the report on this project in last year's Annual Review, the polarization and the differential cross section for neutrons scattered from F, Na, Mg, Al, and P showed structure when considered as functions of neutron energy.[1,2] This observed structure, measured with an energy spread of about 125 keV, was characterized by resonance-like peaks having widths of 100—150 keV and spacings between 300 and 400 keV. More recent measurements of the total neutron cross sections of F, Al, and Mg with a smaller energy spread (15—20 keV) at incident energies from 0.5 to 2.2 MeV show structure with widths of the order of the energy spread of the incident neutron beam. When these data are averaged numerically over successively larger energy intervals ΔE, the observed fine structure is almost completely averaged out for $\Delta E \approx 60$ keV; but the remaining gross structure, described in last year's Annual Review and also in Ref. 1, is relatively insensitive to the averaging (Fig. 6) for $\Delta E \lesssim 150$ keV.

A preliminary phase-shift analysis of these data employed an optical-model potential with parameters that are allowed to vary to

[1] A. J. Elwyn, J. E. Monahan, R. O. Lane, and A. Langsdorf, Jr., Nucl. Phys. 59, 113 (1964).

[2] J. E. Monahan, Bull. Am. Phys. Soc. 9, 638 (1964).

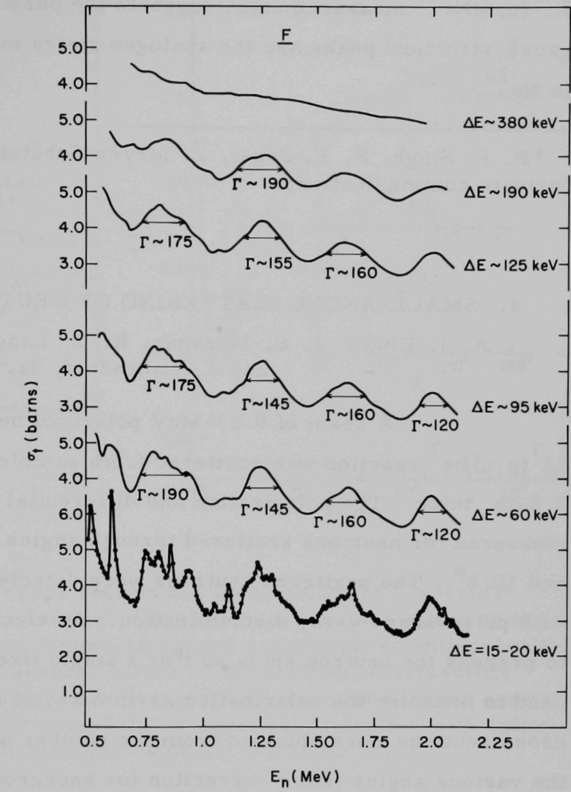

Fig. 6. Total neutron cross sections of F. The different curves show the effect of averaging over successively larger intervals ΔE. The initial data (lowest curves) were measured with an energy spread of about 15—20 keV.

fit the experimental values of the differential and total cross sections at each neutron energy. The energy-dependent behavior found for the real and imaginary parts of the p-wave phase shifts is in qualitative agreement with the energy dependence associated with a resonance contribution to the elastic-scattering amplitude. The polarization data are being included in a more nearly complete phase-shift analysis which may be able to determine the spin and parity of the gross-structure states. These results could be compared with Lemmer's proposed particle-hole description[3] of these states. A comparison of the present data with

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[3] R. Lemmer (private communication).

$F^{19}(p,\gamma)Ne^{20}$ measurements[4] suggests the possibility that some of these gross-structure peaks are the analogue states in F^{20} of the T=1 states in Ne^{20}.

[4] P. P. Singh, R. E. Segel, L. Meyer-Schützmeister, and Z. Vager (private communication).

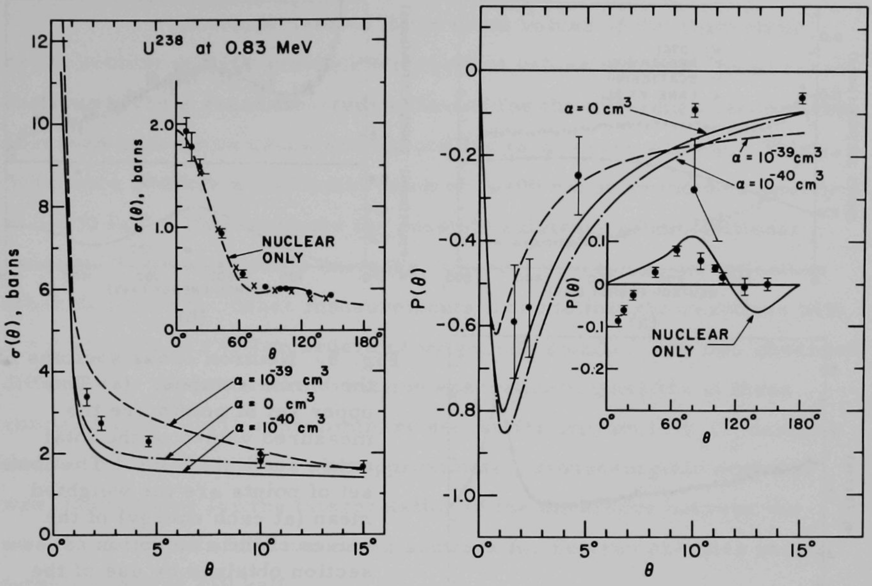
4. SMALL-ANGLE SCATTERING OF NEUTRONS BY URANIUM[1]

A. J. Elwyn, J. E. Monahan, R. O. Lane, F. P. Mooring, and A. Langsdorf, Jr.

A beam of 0.83-MeV polarized neutrons from the $Li^7(p,n)Be^7$ reaction was scattered from samples of natural uranium 0.5-in. thick. The polarization and differential cross section were measured for neutrons scattered through angles of 1.65°, 2.35°, 4.6°, and 10.0°. The scattered neutrons were detected by a liquid scintillator with pulse-shape γ-ray discrimination. An electromagnet was used to precess the neutron spins so that a single fixed detector could be used to measure the polarization asymmetry at any given angle. Absolute cross sections were obtained from the number of neutrons detected at the various angles (after correction for background effects) relative to the number of neutrons incident on the scattering sample. These results (shown in Fig. 7) are discussed in Sec. II.8.

Two subsidiary experiments served as partial checks on the accuracy. Measurements on neutrons scattered through ~2° by polyethylene gave zero polarization and an n-p cross section within 5—10% of the theoretical value. And using banks of BF_3 counters in

[1] R. O. Lane, A. J. Elwyn, J. E. Monahan, A. Langsdorf, Jr., and F. P. Mooring, Bull. Am. Phys. Soc. 10, 498 (1965).



(a) (b)

Fig. 7. The differential cross section and polarization of 0.83-MeV neutrons scattered from uranium. (a) The experimental values of the differential cross section (shown as points) are compared with calculations (solid curves) for several values of the neutron polarizability (in cm³). The inset shows a similar comparison for the larger scattering angles. (b) A comparison of the measured polarization with calculations based on the indicated values of the polarizability.

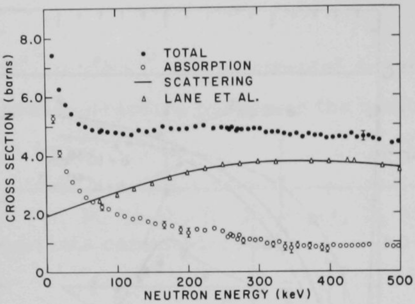
shielding tanks for scattering angles down to $\sim 10^{\circ}$ gave differential cross sections within $\sim 10\%$ of the values measured with the liquid scintillator.

5. NEUTRON CROSS SECTIONS OF THE BORON ISOTOPES

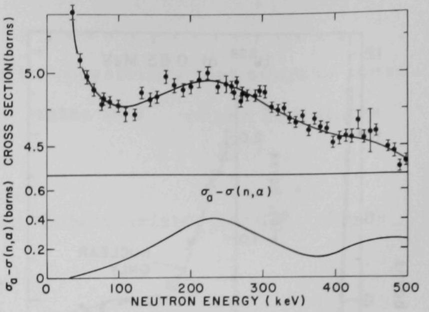
F. P. Mooring and J. E. Monahan

The self-indication counter system[1] was used to measure the neutron cross sections of the boron isotopes in the energy interval

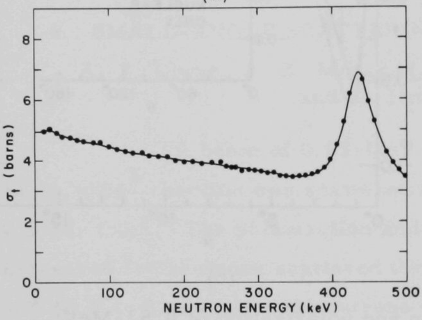
[1] Described by A. Langsdorf in Fast Neutron Physics, Part I (Interscience Publishers, Inc., New York, 1960), p. 739.



(a)



(b)



(c)

Fig. 8. Neutron cross sections of the boron isotopes. (a) The upper set of points are the measured values of the total cross section of B^{10}. The lower set of points are the weighted mean (at each energy) of the values of the absorption cross section obtained by use of the two sets of boron samples. The curve represents the difference between smooth curves drawn through the data for the total and absorption cross sections. The triangles are the values of the integrated scattering cross section of B^{10} obtained from the differential scattering measurements of Lane et al. (Ref. 2). (b) The upper curve shows the total cross section for B^{10} on an expanded scale. The lower curve is the cross section $[\sigma_a - \sigma(n,a)]$ described in the text. (c) The measured total cross section for B^{11}. These data have been corrected for the subsequent absorption by B^{10} of scattered neutrons.

from 10 keV to 500 keV (Fig. 8). Boron samples of normal isotopic abundance and samples enriched in B^{10} to a relative isotopic abundance of 93% were used in order to derive values for the total cross sections of B^{10} and B^{11}. Independent values of the absorption cross section were obtained for each type of sample; results for the two sample types are in satisfactory agreement. The present results are also in good agreement with the scattering cross sections of B^{10} and B^{11} measured independently by Lane, Elwyn, Langsdorf, and Mooring.[2]

[2] R. O. Lane, A. J. Elwyn, A. Langsdorf, Jr., and F. P. Mooring (private communication).

A comparison of the present values of the absorption cross section σ_a with previously measured values of the $B^{10}(n, \alpha)$ cross sections gives a resonance-type behavior for the difference between the observed absorption cross section and the (n, α) cross section. This difference reaches a maximum value of $\sim$400 mb at an incident energy of $\sim$230 keV. This suggests the possible existence of an additional reaction $B^{10}(n, x)$ at these energies, where x represents an emission other than α or n. Other measurements indicate that the reactions with $x = p$ or γ are one to two orders of magnitude smaller than this observed difference. The only other reaction energetically possible at these energies is $B^{10}(n, t)$; a preliminary search for tritium in B_2O_3 samples that have been irradiated with approximately monoenergetic neutrons was inconclusive for the interpretation of the difference between the measured values of the two cross sections for neutron energies in the neighborhood of 230 keV.

The shape of this difference in cross sections $[\sigma_a - \sigma(n, \alpha)]$ is that of a resonance formed by p-wave neutrons. Thus this result may indicate a positive-parity level at an excitation energy of 11.68 MeV in B^{11}.

6. UNBOUND NUCLEAR LEVELS IN THE KEV REGION: POSSIBLE STRUCTURE OF THE 7.46-MEV LEVEL IN ^{7}Li

Carl T. Hibdon

The equipment and techniques that have been used to study unbound nuclear levels in the keV region by neutron transmission have been used in the study of the resonance in ^{6}Li near 250 keV, which corresponds to the level in ^{7}Li at 7.46 MeV. In the past, measurements by various experimenters using large neutron energy spreads have yielded a width of 90 to 120 keV for this resonance. Many measurements on ^{6}Li metal samples have been made here at Argonne by use of neutron energy spreads ranging from what is thought to be less than a keV to about 9 keV. When large neutron energy spreads are used, one large resonance about 90 keV in width is observed as it has been all along by other experimenters. However, when small energy spreads are used, the results obtained indicate that the large resonance comprises a number of narrow peaks. Many curves have been obtained by use of small energy spreads and all show the narrow peaks. The peaks "wash out" as the neutron energy spread is increased. All checks made to pin the effect on instrumental difficulties have failed to account for the narrow peaks; on the other hand, it is not yet established that these narrow peaks represent genuine nuclear levels.

7. STUDIES OF $B^{10}(p,p')$

P. P. Singh and R. E. Segel

By use of gamma-ray singles and coincidence measurements, the decay of various states of B^{10} and the yield curves of these states from inelastic scattering have been studied. New results on the decay properties are: (1) The intensities of the 0.42-, 1.43-, and 2.15-MeV transitions from the 2.15-MeV state are in the ratio 50:25:25. (2) The upper limit on the branch from the 3.58- to the 1.74-MeV state is 0.5%. (3) The 5.16-MeV state decays by α emission about 30% of the time. The yield curves usually show only rather broad structure and there are significant variations in the feeding of the various states. It is found that the yield of the T=0 states averages 5—10 times the yield of the T=1 states.

8. INTERACTION OF B^{11} WITH 0.5—4-MEV PROTONS

R. G. Allas, S. S. Hanna, and R. E. Segel

Analysis of the radiations from the various exit channels (namely elastically scattered protons, gamma rays following inelastic scattering, capture gamma rays, neutrons, and alpha particles) has led to identification of nine separate states in C^{12} and assignment of their quantum numbers and partial widths. By combining these results with a few other states previously identified by others, it has been possible to compare in detail the observed level spectrum in C^{12} between 15 and 19.5 MeV excitation with the spectrum predicted by the particle-hole model. It is found that every state predicted by the particle-hole model is observed within about 1.5 MeV of its predicted position. However, additional states are present and these are presumably due to higher configurations. Where one of these additional states has the same quantum numbers as a state that is predicted by the particle-hole model, the angular-distribution data indicate that the single-particle configuration is shared by these two states.

9. STUDIES OF CORONA CURRENT

A. Langsdorf, Jr., and R. B. Wehrle*

The accompanying figure presents some experimental results which show that a corona discharge in a mixture of nitrogen and carbon dioxide changes in character if the discharge is maintained for an extended period of time in a small closed system. More surprising, if the current flow is interrupted for several days, a subsequent test of this same sample of gas shows that the character of the corona has

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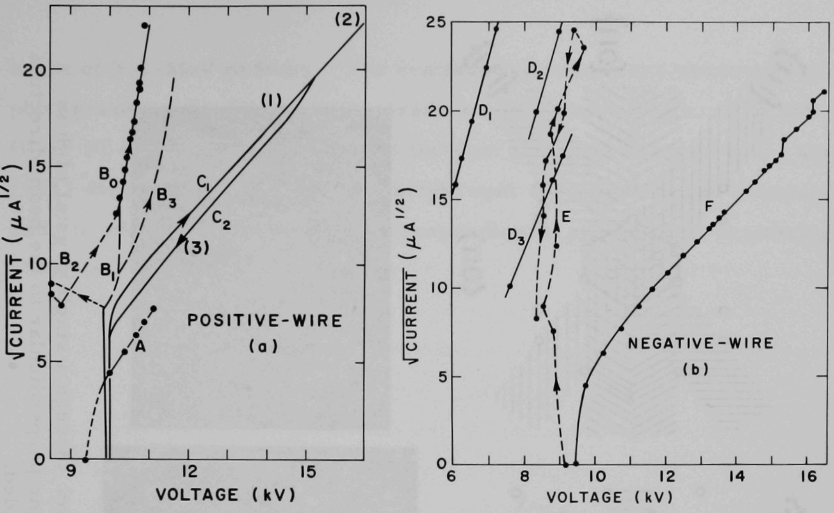
*Remote Control Engineering, ANL.

undergone a further drastic change. These various changes are certainly related to changes in the chemical composition of the gas brought about by, or subsequent to, the discharge itself. The effects probably depend sensitively upon minor and transitory constituents of the gas mixture. For this reason, and because corona is a complicated phenomenon whose theoretical interpretation is incomplete even in simpler cases, a detailed understanding of the present observations is unlikely to be obtained. However, N_2-CO_2 mixtures are commonly used as the dielectric insulation in pressurized electrostatic generators, so that observations such as these may be very pertinent to an improved understanding of the operating behavior—and misbehavior—of such machines.

A substantial part of each of the curves A, C, D, and F (Fig. 9) is very nearly a straight line. Such an appearance for data plotted in this particular way is strongly indicative that the current flow is limited by space-charge of ions of one sign only. Such space-charge limiting is probably a key factor in determining the behavior of all "normal" corona-like discharges. The quite different appearance of curves B and E, taken together with the visibly greater luminosity of these discharges, suggests that in these cases space-charge limiting is not so dominant. Probably photoionization creates a mixture of positive and negative ions which permits an enhanced current flow at a given voltage. These discharges should probably be called glow discharges, such as are well known at lower pressures, but are not often observed at 1 atm pressure.



(a) (b)

Fig. 9. Corona current between a wire and a cylinder in a closed system containing 80% N_2, 20% CO_2 at 1 atm. (a) Positive-wire corona. Curve A is for fresh gas. After "conditioning" by running at ~60 μA for about 30 min, the discharge became much more luminous and the curves became somewhat unreproducible as illustrated by curves B_1-B_0, B_2-B_0, and B_3 obtained in different tests. After "aging" the same gas for several days (no current flowing), curve C_1-C_2 was followed—with noticeable sparking initially at (1), later at (2), and finally around (3). Curves A and C were fairly reproducible. (b) Negative-wire corona for the same gas and equipment. Curve D_1 is for fresh gas. "Conditioning" with several hundred microamperes for about 30 min shifts the curve first to D_2 and then D_3. The negative-wire current seems to flow only from a few luminous points on the wire and fluctuates if the number or positions of the points changes. Curve E was obtained just after the same "positive-wire conditioning" that gave curve B. Curve F was obtained for the "aged" gas that gave the positive-wire curve C.

10. CHANNELLING OF 3.6-MEV PROTONS THROUGH MONOCRYSTALS OF Si

R. E. Holland and J. P. Schiffer

The recently discovered phenomenon of channelling was studied by bombarding a crystal of Si 3 mils thick with a collimated

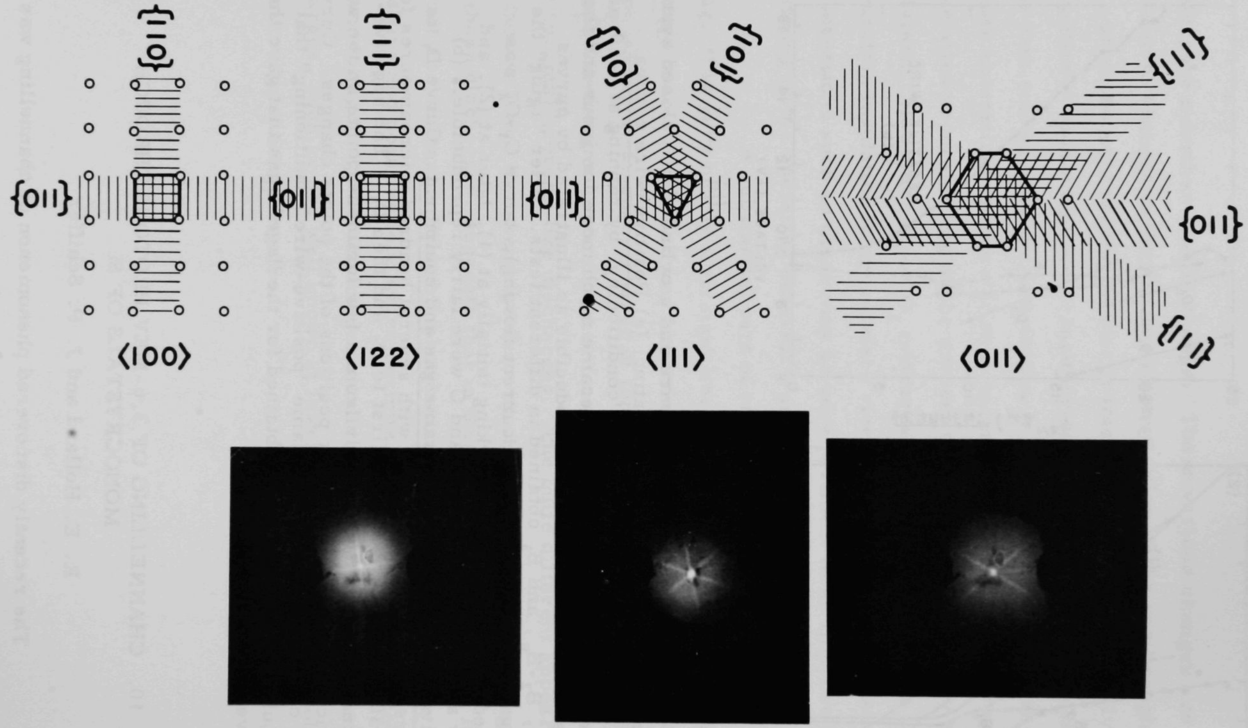


Fig. 10. Observed pattern of the proton beam after transmission through a single crystal of Si in various orientations. The projection of the crystal onto a plane perpendicular to the beam direction is also shown for each case, with the "channeling" planes shaded.

beam of 3.6-MeV protons. The scattered protons were observed by photographing the fluorescence produced on a quartz plate. The patterns (Fig. 10) observed with the beam incident along the ⟨111⟩, ⟨122⟩, and ⟨011⟩ directions show a central bright spot corresponding to "channelling" and, in addition, bright lines corresponding to preferential scattering along low-order crystal planes.

C. RESEARCH AT THE 12-MEV TANDEM VAN DE GRAAFF

The operation of the tandem Van de Graaff is now on a 152-hr/week schedule. In addition to use by the Physics Division, the tandem facility is also used by members of the Chemistry Division and the Solid State Science Division. A program formally initiated in January 1964 makes the tandem available to qualified users from outside Argonne. Ten groups from other institutions have conducted experiments with this facility as of May 1965.

All major pieces of apparatus planned for the initial phase at the tandem are now in operation. The broad-range magnetic spectrograph is used for about 30% of the experimental program. The pulsed beam has been used for studies of (d, n) reactions and for the measurement of lifetimes of nuclear states. The scattering chambers and γ-ray angular-correlation apparatus are in routine operation. The ASI-2100 computer has been installed and is intensively used for on-line operation with both the tandem and the 4.5-MeV Van de Graaff. This computer has a communication link with the CDC-3600 computer, whose capacity and speed can now be utilized for on-line experiments.

A second phase of instrumental development for the tandem is well under way. The plans for a polarized ion source are completed and construction of the source is proceeding rapidly. A program for the development of unpolarized sources has started and will be continued. A high-resolution germanium-diode detection system is now in use and further refinements will be made. A second on-line computer (ASI-210) and an associated core-storage unit of very large size will be installed in the fall of 1965.

1. INSTALLATION AND OPERATION OF THE TANDEM VAN DE GRAAFF ACCELERATOR

Jack R. Wallace

The tandem has operated 5451 hours from 1 April 1964 to 31 March 1965. This makes a total of 14 656 hours on this accelerator. The tandem is operating on a schedule of 152 hours per week. An additional technician is currently being hired so that the accelerator can be operated 24 hr/day, 7 days/week. In addition to maintaining a good operating schedule for the scientific research program of the division, the operational group also modifies and improves the tandem and its associated equipment so that its performance meets the increased demands of its users. Areas of concern are beam stability, beam current, beam energy, types of beam available, and maximum operating time.

Many improvements have been made in the past year. (1) Inclined-field accelerating tubes were installed and new resistors were made for the insulating column. Reliable operation up to 7 MV on the high-voltage terminal has been achieved during the 4353 hours of operation to date. (2) A kit to increase the transmission at the input of the accelerator has been purchased and will be installed soon. The larger beam current results from matching the optics of the ion source to the optics of the accelerating tube. (3) To increase the ion current available for injection into the tandem, another einzel lens has been added at the output end of the charge-exchange canal in the duoplasmatron ion source. Other types of ion sources and modifications of the duoplasmatron ion source are being developed. (4) In the He injector, new beam-alignment components and a local control panel have been added, and the power supplies for the quadrupole magnet, the resistor units for the column, and the circuitry for the source and terminal have been modified. Other improvements include (5) new actuators for the Faraday cups, (6) grounding bars to protect the motor driving the belt, and (7) a nuclear-magnetic-resonance system for measuring the field in the 90° magnetic analyzers. In addition to these changes in the accelerator itself, (8) a second 18-in. scattering chamber has been completed and put into use, and (9) the ASI-2100 has been used as an on-line computer for experiments done with the tandem.

Further plans include installation of a source of polarized ions, additional on-line computing equipment, and a foil-type stripping system in the high-voltage terminal.

2. THE PHYSICS DIVISION ON-LINE COMPUTING SYSTEM (PHYLIS)

D. S. Gemmell

The PHYLIS system passed its acceptance tests during the past year and is now in almost continuous use as a means of data acquisition and reduction at the Tandem and 4-MeV Van de Graaff accelerators. The system has been augmented by the addition of a large display oscilloscope with a light pen, an additional dual ADC unit, and remote control boxes to operate the computer.

The oscilloscope facility finds extensive use in the reduction of data both on-line and off-line. By using it, the time-consuming operations of plotting each spectrum, deriving channel numbers for computation purposes, and then feeding this information with the original data back into a computer are bypassed.

The tandem Van de Graaff station has been used extensively for data acquisition, particularly for multiparameter analysis. The link to the CDC-3600 computer is in use for pulse-height sorting into 256×256-channel distributions. This link is still not available for use on an on-line interrupt basis because of delays in making necessary changes to the 3600 monitor program. However, the link is used when the two computers are scheduled jointly.

The PHYLIS system has been used at the 4-MeV Van de Graaff mainly in conjunction with neutron-scattering measurements for which the "on-line" capability is of great value in evaluating the progress of the experiments.

Because the work load on the system is so high, another processor has been added. This is an ASI-210 which is very similar to the existing ASI-2100 in the system. It has been possible to redistribute the external devices of the system in a more efficient manner and to avoid scheduling problems which we had when the system was needed simultaneously by both accelerators. It also provides a means of de-bugging programs off-line in preparation for on-line use.

3. PULSED-BEAM EXPERIMENTS AT THE TANDEM

a. Pulsed-Beam Apparatus

F. J. Lynch

Minor changes in this apparatus make the operation more reliable and convenient. Also, a circuit has been added to increase the time between beam bursts from the usual time of 266.7 nsec to 533.3, 1066.7, or 2133.3 nsec. This facilitates measuring longer lifetimes and unscrambling neutron time-of-flight spectra with low-energy groups (which have correspondingly long flight times). The expansion of the time base is achieved by eliminating some of the pulses that excite the preacceleration chopper.

b. Pulsed-Beam Measurements of the Lifetimes of Nuclear States

R. E. Holland, F. J. Lynch, and K.-E. Nystén

The lifetimes of $d_{3/2}$ hole states in the region where the $f_{7/2}$ shell is being filled have been measured.[1] These states, which decay by an M2 transition to the ground state, have been observed in Ca^{41}, Ca^{43}, Sc^{43}, Sc^{45}, and Sc^{47}. In each case, the lifetime is from 100 to 400 times the single-particle estimate. Theoretical work by Lawson and Macfarlane shows that this can be explained by reasonable assumptions about the wave functions of these states.

[1] R. E. Holland, F. J. Lynch, and K.-E. Nystén, Phys. Rev. Letters 13, 241 (1964); Bull. Am. Phys. Soc. 9, 650 (1964); R. E. Holland, F. J. Lynch, and H. M. Mann, Bull. Am. Phys. Soc. 10, 119 (1965).

c. Measurements of Proton Strength Functions[1]

A. J. Elwyn, A. Marinov, and J. P. Schiffer

The average yields of neutrons from (p, n) reactions on thick targets have been measured, and reduced cross sections which are related to the proton strength functions have been obtained from the results. Measurements were made on 30 elements in the mass region $96 \leq A \leq 209$ at energies between 5.5 and 9.5 MeV by use of the ANL tandem accelerator. Previous measurements[2] in the mass region between A = 40 and 150 indicated a broad maximum in the proton strength function at A = 68; it is probably the 3s proton single-particle state. The present results for the reduced cross section $\mathcal{S}$ are shown in Fig. 11. Also shown in the figure are predictions based on an optical model suggested by Perey.[3] These calculations are in reasonably good agreement with the measurements—in magnitude if not in detail. The experimental decrease in $\mathcal{S}$ between A = 125 and 138 is quite well fitted by the calculations although the calculated decrease is more gradual. Between A = 145 and 180 the experimental points show a peak, <u>not</u>

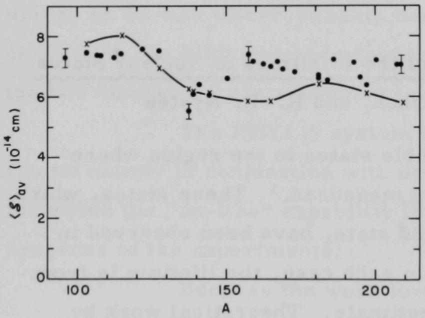


Fig. 11. The reduced cross section $\mathcal{S}$ (defined in Ref. 2) as a function of mass number A. The experimental points are the solid circles. Calculations based on an optical model (Ref. 3) are shown as the solid lines and the points marked x.

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[1] A. J. Elwyn, A. Marinov, and J. P. Schiffer, Bull. Am. Phys. Soc. <u>10</u>, 495 (1965).

[2] J. P. Schiffer and L. L. Lee, Jr., Phys. Rev. <u>109</u>, 2098 (1958).

[3] F. Perey, Phys. Rev. <u>131</u>, 745 (1963).

reproduced by the calculations. Further optical-model calculations indicate that the region around A = 110 is dominated by a peak in the p-wave strength function, and that in the region of $A \approx 180$ the d-wave (and possibly also the s-wave) strength function is predominant. The disagreement between calculations and measurements in the region from A = 150 to 190 may be associated with the fact that many of the nuclei in this mass region are strongly deformed.

d. The $Mg^{24}(d,n)Al^{25}$ and $Si^{28}(d,n)P^{29}$ Reactions

D. S. Gemmell, L. L. Lee, Jr., S. Puccina,* J. P. Schiffer, and A. B. Smith*

In comparison with the (d, p) reaction, (d, n) stripping reactions have not been studied in great detail—largely because of the experimental difficulties involved in obtaining good energy resolutions for fast neutrons. In the present work, the pulsed deuteron beam of the Argonne tandem Van de Graaff was used with a final energy resolution

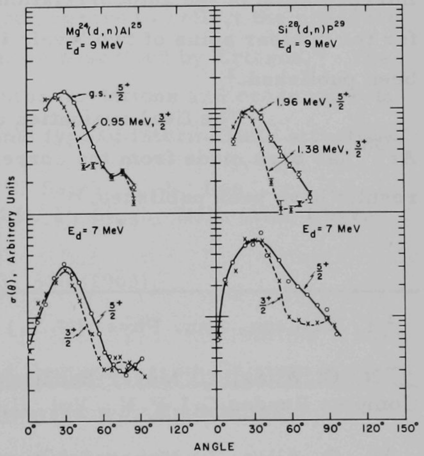

Fig. 12. Differential cross sections for the reactions $Mg^{24}(d,n)$ and $Si^{28}(d,n)$ at 7 and 9 MeV. These illustrate the J dependence for ℓ_p=2 transitions.

*Reactor Physics Division.

width of ~150 keV. Both 7.0- and 9.0-MeV deuterons were used. Angular distributions were determined for a number of final states; their analysis is in progress. J-dependent differences between $\ell = 2$, $J = \frac{3}{2}$ and $\ell = 2$, $J = \frac{5}{2}$ states are clearly observed; these are similar to the effects seen in the (d, p) reaction. Some preliminary results are shown in Fig. 12.

4. CHARGED-PARTICLE REACTIONS AT THE TANDEM

a. (p, α) Reactions on K^{39} and K^{41}

R. G. Allas, L. Meyer-Schützmeister, and D. von Ehrenstein

The complete analysis of our data on the $K^{39}(p,\alpha)Ar^{36}$ reaction enabled us to estimate the amount of direct interaction involved in this reaction in terms of Ericson's fluctuation theory.[1] Careful interpretation of the autocorrelation functions suggests upper limits for the nuclear spins of two levels in Ar^{36}; parts of these results have been published.[2]

The final evaluation of the level schemes of Ar^{36} and Ar^{38} has been made from the corresponding (p, α) reactions and the results have been published.[3]

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[1] T. Ericson, Ann. Phys. (N. Y.) 23, 390 (1963).

[2] R. G. Allas, L. Meyer-Schützmeister, and D. von Ehrenstein, Comptes Rendus C.I.P.N., Vol. II, 695 (Paris, 1964).

[3] R. G. Allas, L. Meyer-Schützmeister, and D. von Ehrenstein, Bull. Am. Phys. Soc. 9, 553 (1964); Nucl. Phys. 61, 289 (1965).

b. The Scattering of Protons by Ni^{58}

A. Elwyn, L. L. Lee, Jr., L. Meyer-Schützmeister, J. E. Monahan, R. E. Segel, P. P. Singh, and Z. Vager

Ni^{58} foils, approximately 25 keV thick to 10-MeV protons, were bombarded with protons and the resulting proton spectra were observed with silicon detectors.[1] Data were taken at six angles in 25-keV steps over a range of proton energies from 8 to 11 MeV. Yield curves with a statistical accuracy of $\sim$0.5% at each point have been extracted at each angle for the elastic group and for the seven most energetic inelastic groups (including one unresolved doublet). Auto-correlations and cross correlations have been calculated for these data. The results for the proton yields leading to the second, third, fourth, fifth, sixth (unresolved), and seventh excited states indicate that there are at least two distinct coherence widths. One width is narrower than the 25-keV incident-energy spread used in these measurements while the other coherence width is about 100 keV. The narrower width is present only in the autocorrelations and appears to reflect the presence of statistical fluctuations similar to those described by Ericson.[2] The broader width is present in both the autocorrelations and cross correlations and indicates the presence of some type of intermediate structure.

[1] J. E. Monahan, A. J. Elwyn, R. E. Segel, L. L. Lee, Jr., L. Meyer-Schützmeister, Z. Vager, and P. P. Singh, Bull. Am. Phys. Soc. 10, 104 (1965); 10, 495 (1965).

[2] T. Ericson, Ann. Phys. (N. Y.) 23, 390 (1963).

c. Elastic Scattering of Protons and Deuterons from Calcium Isotopes

L. L. Lee, Jr., A. Marinov, and J. P. Schiffer

The experimental results[1] for 9- and 12-MeV protons and deuterons elastically scattered from enriched isotopic targets of

[1] L. L. Lee, Jr., A. Marinov, and J. P. Schiffer, PHY Annual Review 1963—1964, ANL-6879, p. 45.

Ca^{42}, Ca^{44}, and Ca^{48} have been analyzed in terms of the optical-model potentials. In particular, the dependence of the real depth of the proton potential on a symmetry term[2] has been studied. The symmetry potential was found to be 21 and 23 MeV for 9- and 12-MeV protons, respectively, in fair agreement with Perey's[2] results. The scattering of the 9-MeV deuterons from the three isotopes can be fitted reasonably well by using optical-model parameters that fit the scattering from Ca^{40},[3] although "best fit" parameters have also been obtained. The scattering of the 12-MeV deuterons can be reproduced by using a different set of parameters for each isotope.

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[2] F. G. Perey, Phys. Rev. 131, 746 (1963).

[3] R. H. Bassel, R. M. Drisko, G. R. Satchler, L. L. Lee, Jr., J. P. Schiffer, and B. Zeidman, Phys. Rev. 136, 960 (1964).

d. The Elastic Scattering of Deuterons by Ti^{48}

C. Mayer-Böricke and R. H. Siemssen

The elastic scattering of deuterons by Ti^{48} has been measured at 1-MeV intervals from 6 to 13 MeV. Until recently there has been a scarcity of data on deuteron scattering in this energy region, and comprehensive optical-model[1,2] studies have been restricted to energies above 11 MeV. The present data are being analyzed in terms of the optical model to investigate whether anomalies exist in this energy region.

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[1] E. C. Halbert, Nucl. Phys. 50, 353 (1964).

[2] C. M. Perey and F. G. Perey, Phys. Rev. 132, 755 (1963).

e. Scattering of Deuterons by Mg^{24} and the $Mg^{24}(d,p)Mg^{25}$ Reaction

C. Mayer-Böricke and R. H. Siemssen

For a detailed study of an apparent anomaly[1] in the scattering of deuterons from Mg^{24}, the $Mg^{24}(d,d)Mg^{24}$, $Mg^{24}(d,d')Mg^{24}$, and $Mg^{24}(d,p)Mg^{25}$ reactions have been investigated in the energy region between 6 and 13 MeV. Angular distributions were obtained at bombarding energies 1 MeV apart and yield functions were measured in 50-keV steps at 90° and 150°. The study of the energy dependence of the (d, p) reaction is of interest for the understanding of strong-coupling effects that are expected to be important in the $Mg^{24}(d,p)Mg^{25}$ reaction.

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[1] C. Mayer-Böricke, C. R. Santo, and U. Schmidt-Rohr, Nucl. Phys. 33, 36 (1962).

f. The $B^{10}(d,p)B^{11}$ Reaction

R. H. Siemssen and L. L. Lee, Jr.

As a test of the DWBA theory for a very light nucleus, the $B^{10}(d,p)B^{11}$ reaction has been studied in the energy range from 2 to 12 MeV. In addition, the elastic deuteron scattering of B^{10} has been measured at the corresponding energies and a measurement of the scattering of protons by B^{11} is in progress. The measured angular distributions change slowly and systematically with bombarding energy. Similarly, the differential yield curves at a laboratory angle of 50°, measured in 100-keV steps from 5.0 to 12 MeV show no significant fluctuations.

g. Study of the Isobaric-Spin-Forbidden Reaction $C^{12}(d,\alpha)B^{10}$ (1.74 MeV, T = 1)

R. G. Allas, L. Meyer-Schützmeister, and D. von Ehrenstein

We have extended our earlier investigations[1] of the reaction $C^{12}(d,\alpha)B^{10}$ populating the first T=1 state in B^{10} into the deuteron energy range from 11.0 to 13.0 MeV. The α group of the isobaric-spin-forbidden reaction was measured with the magnetic spectrograph. Only with the high energy resolution of this instrument could the often very weak α group be obtained rather unperturbed by the (d,α) reaction in the O^{16} impurity in the C target. In the earlier work[1] in which we studied the energy range from 9.0 to 11.0 MeV, the angular distribution was nearly symmetric around 90°; but in the higher energy region which we studied since then, the angular distribution is markedly changed—it is strongly peaked in the forward direction. At a deuteron energy of 12.5 MeV, the angular distribution for the α group of interest shows its largest differential cross section of about 0.3 mb/sr at $\theta_{lab} = 20^{\circ}$. It falls off sharply with increasing angle and disappears in the background at all measured angles larger than 30°. We have measured at angles up to $\theta_{lab} = 147^{\circ}$ in steps of about 20°. The strongly forward-peaked angular distribution starts to appear at a deuteron energy of about 11.3 MeV and increases appreciably with energy. It shows that the isobaric-spin-forbidden reaction does not proceed exclusively via compound-nucleus formation.

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[1] R. G. Allas, J. R. Erskine, L. Meyer-Schützmeister, and D. von Ehrenstein, Bull. Am. Phys. Soc. 8, 538 (1963).

h. (He^3,α) Reactions on Medium-Weight Nuclei

T. H. Braid and L. Meyer-Schützmeister

Energy levels of isotopes in the Ti-Zn region are being studied by the (He^3,α) reaction at incident energies of 12 to 14 MeV (mainly E = 13 MeV). The α particles are recorded in a broad-range magnetic spectrograph with an energy resolution width (determined by target thickness) of 30—60 keV. The spectra from targets of Ti^{50}, Cr^{52}, Fe^{54}, and Fe^{56} show a number of α groups corresponding to levels over a 9-MeV range of excitation energies. The complex spectrum from V^{51} shows more than 30 groups. Angular distributions have been measured for V^{51} and Fe^{56} from 8^o to 50^o. The levels at 4.25 MeV in Fe^{53} and at 7.79 MeV in Fe^{55} agree well with the $T_0 + \frac{1}{2}$ isobaric-analogue states known from the (p, d) and (d, t) reactions. In V^{50}, the states at 4.83, 6.40, 7.54, and 8.08 MeV are at the energies predicted for the T=3 analogue states of the 0^+, 2^+, 4^+, and 6^+ states in Ti^{50}.[1] The angular distributions for these states agree with the predictions of a DWBA calculation for ℓ=3 pickup (with a small ℓ=1 admixture in one case), and the relative spectroscopic factors extracted from the calculation are in good agreement with those obtained from the excitation of the analogous states in Ti^{50} by the reaction $V^{51}(d,He^3)Ti$.[2]

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[1] T. H. Braid and L. Meyer-Schützmeister, Bull. Am. Phys. Soc. 10, 480 (1965).

[2] B. Zeidman and T. H. Braid, Bull. Am. Phys. Soc. 10, 479 (1956).

i. (He^3,d) Reactions on Zinc Isotopes

L. L. Lee, Jr., R. H. Siemssen, and B. Zeidman

The structure of the low-lying levels of the gallium isotopes is being studied by means of the (He^3,d) reaction. The experiment is being performed in the 18-in. scattering chamber with the use of a dE/dx-E telescope for particle identification. Most of the known levels below 2 MeV in Ga^{67} and Ga^{69} have been observed.

j. Analogue States in Sc^{49}

K. W. Jones,* L. L. Lee, Jr., A. Marinov, and J. P. Schiffer

The scattering of protons from Ca^{48} reveals strong resonances at 1.95, 4.05, 6.07, and 6.45 MeV. These appear to be the isobaric-spin analogues of those Ca^{49} states that are prominent in the $Ca^{48}(d,p)Ca^{49}$ reaction. The shapes of the resonances and their widths are in agreement with the angular momenta and spectroscopic factors of the states in Ca^{49}. The $Ca^{48}(p,n)Sc^{48}$ reaction also exhibits prominent resonances at all but the very broad 4-MeV resonance. This is the lightest nucleus in which a detailed study of analogue states has been made; the correspondence between the "analogue" and the "normal" states is as good as in heavier nuclei.

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*Brookhaven National Laboratory.

5. DEPENDENCE OF THE ANGULAR DISTRIBUTION OF DIRECT REACTIONS ON THE TOTAL ANGULAR MOMENTUM TRANSFER

The angular distribution of (d,p) stripping reactions has been used for more than ten years to measure the orbital angular momentum transferred in the reaction. Early in 1964 it was discovered that the $\ell=1$ stripping reactions on medium-weight nuclei can also be used to determine the total angular momentum transferred; a sharp dip at backward angles is characteristic of $\Delta J = \frac{1}{2}$ transitions and this dip is absent for $\Delta J = \frac{3}{2}$ transitions. Further experiments on (d,p) reactions as well as other direct reactions, carried out during the past year, have revealed that J-dependent effects seem to be present in most cases.

a. Dependence of the Angular Distribution of the (d,p) Reaction on the Total Angular-Momentum Transfer

L. L. Lee, Jr., A. Marinov, C. Mayer-Böricke, and J. P. Schiffer

J-dependent effects in the proton angular distribution from the (d,p) reaction have been found throughout the periodic table.

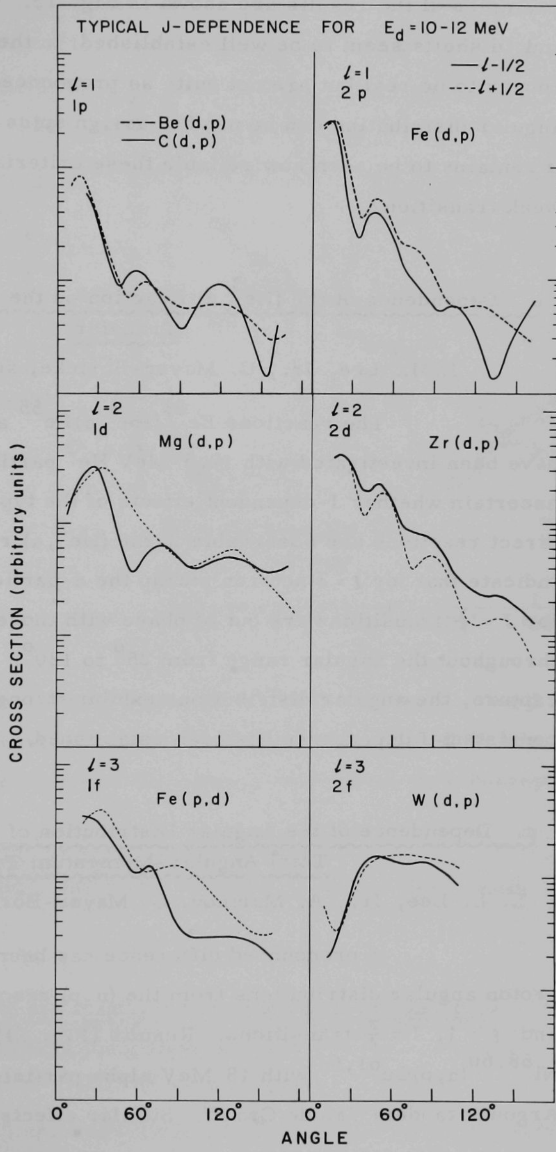

Fig. 13. Examples of typical J dependence observed in (d, p) reactions for the angular momenta and shell-model orbitals indicated. In all cases the results for $\Delta J = \ell + \frac{1}{2}$ is indicated by a dashed line and the angular distribution for $\Delta J = \ell - \frac{1}{2}$ by the solid line. For the 1f shell, results are shown for $Fe^{56}(p,d)Fe^{55}$ at a proton energy corresponding to the deuteron energies used for the other experiments.

Examples of the results are shown in Fig. 13. The effects in the 2p and 1d shells seem to be well established; in the other shells the effects appear to be real but are not quite so pronounced. The characteristic angular distribution can be used to assign spins for strong transitions. It remains to be seen how reliable these criteria are when applied to weak transitions.

b. Dependence of the (He^3, α) Reaction on the Total Angular Momentum Transfer

L. L. Lee, Jr., C. Mayer-Böricke, and R. H. Siemssen

The reactions $Fe^{56}(He^3, \alpha)Fe^{55}$ and $Ni^{60}(He^3, \alpha)Ni^{59}$ have been investigated with 17.5-MeV He^3 particles in an effort to ascertain whether J-dependent effects of the type observed in other direct reactions are observable in the (He^3, α) reaction. Our results indicate that for $\ell = 3$ neutron pickup the α-particle angular distributions for $J = \frac{5}{2}$ transitions are out of phase with those for $J = \frac{7}{2}$ transitions throughout the angular range from 25° to 120°. For $\ell = 1$ neutron capture, the angular distributions exhibit strong oscillations, but no consistent J dependence has been established.

c. Dependence of the Angular Distribution of the (α, p) Reaction on the Total Angular-Momentum Transfer

L. L. Lee, Jr., A. Marinov, C. Mayer-Böricke, and J. P. Schiffer

A pronounced difference has been found between the proton angular distributions from the (α, p) reaction for $\ell = 1$, $J = \frac{1}{2}$ and $\ell = 1$, $J = \frac{3}{2}$ transitions. Results (Fig. 14) for the reactions $Ni^{58,60}(\alpha, p)Cu^{61,63}$ with 18-MeV alpha particles were obtained at the Argonne tandem Van de Graaff. Similar effects were found in examining

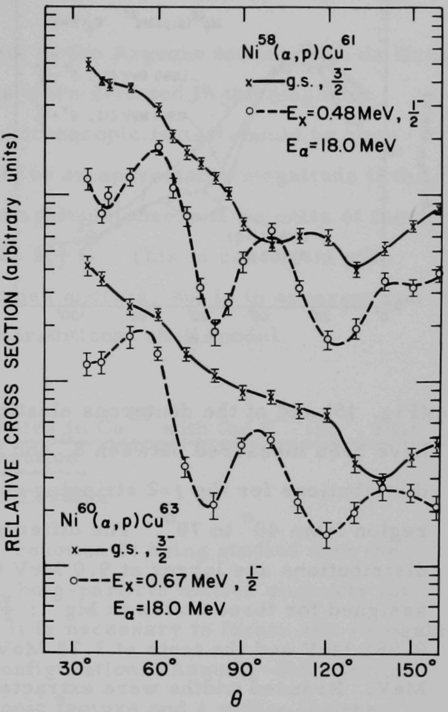

Fig. 14. Proton angular distributions measured for the reactions $Ni^{58,60}(\alpha,p)Cu^{61,63}$ to final states of known spin. Final states of spin $\frac{1}{2}^-$ are indicated by open circles and dashed lines, while the results for states of spin $\frac{3}{2}^-$ are shown as crosses and solid lines.

the work of Yamazaki et al.[1] for ℓ=2 transitions in the 1d shell. The J dependence in the (α, p) reaction appears to be more pronounced than in the (d, p) reaction and holds promise of becoming a very useful spectroscopic tool.

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[1] T. Yamazaki, M. Kondo, and Y. S. Yamabe, J. Phys. Soc. Japan 18, 720 (1963).

d. J Dependence of ℓ=2 Angular Distributions from the (d, p) Reactions on Mg Isotopes

D. Dehnhard and J. L. Yntema

With the 60-in. scattering chamber at the tandem accelerator, angular distributions of various proton groups from the (d, p) reaction

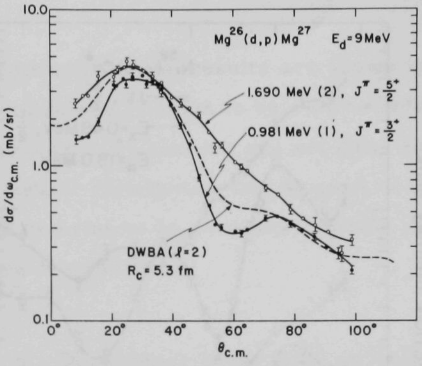

Fig. 15. Angular distributions from the reaction $Mg^{26}(d,p)Mg^{27}$ at E_d = 9.0 MeV. The angular distribution (open circles) from the second excited state was multiplied by 1.82.

(Fig. 15) and of the deuterons elastically scattered from $Mg^{24,25,26}$ have been measured between 8° and 90° at 9.0 and 11.0 MeV. The distributions for the ℓ=2 stripping show strong J dependence in the region from 40° to 70°. The differences between the j=3/2 and j=5/2 distributions are larger at 9.0 MeV than at 11.0 MeV. Spins were assigned for three states in Mg^{27}: $\frac{3}{2}^+$ for the first excited state at 0.981 MeV and the tenth at 3.78 MeV, and $\frac{5}{2}^+$ for the second at 1.690 MeV. Reduced widths were extracted by distorted-wave calculations using optical-model parameters that fitted the angular distributions of the elastically scattered deuterons. The shapes of the calculated differential cross sections are in reasonable agreement with an average of the measured j=3/2 and j=5/2 distributions. The mixtures of ℓ = 2 and ℓ = 0 in the Mg^{25}(d,p) reaction were determined.

6. RESEARCH WITH THE MAGNETIC SPECTROGRAPH

a. The $O^{18}(He^3,d)F^{19}$ Reaction

J. R. Erskine, R. E. Holland, and J. P. Schiffer

Angular distributions for this reaction have been studied[1] in order to determine the spectroscopic factor to the $\frac{1}{2}^-$ first excited

[1] J. R. Erskine, R. E. Holland, R. D. Lawson, M. H. Macfarlane, and J. P. Schiffer, Phys. Rev. Letters 14, 915 (1965).

state of F^{19}. The 10-MeV He^3 beam of the Argonne tandem Van de Graaff accelerator was used; the deuterons were detected in the magnetic spectrograph. The value of this spectroscopic factor should be zero in the strict shell model but would have an appreciable magnitude if the O^{18} nucleus were deformed. The magnitude observed (in units of the $d_{5/2}$ spectroscopic factor) is $S\left(\frac{1}{2}^-\right) \approx 0.25\ S\left(\frac{5}{2}^+\right)$. This is consistent with theoretical expectations for a deformed nucleus, but is in apparent contradiction with the prediction of the traditional shell model.

b. A Study of the Highly Excited States in Ca^{40} with the $K^{39}(He^3,d)Ca^{40}$ Reaction

J. R. Erskine

The $K^{39}(He^3,d)Ca^{40}$ reaction is being studied with the objective of measuring the $d_{3/2}f_{7/2}$ hole-particle matrix elements for the T=0 states of Ca^{40}. To do this it is necessary to locate and recognize the four levels from the $d_{3/2}f_{7/2}$ configuration. Angular-distribution data have been taken and spectroscopic factors and ℓ values for the various states are being extracted with the aid of the DWBA theory. Excited states in Ca^{40} were found at 3.735, 4.488, 5.613, 5.900, 6.024, 6.284, 6.583, 6.750, 6.950, 7.114, 7.530, 7.658, and 7.694 MeV. Many of these states have never previously been seen. Only the states at 3.735, 4.488, and 5.613 MeV excitation were found to have strong ℓ=3 components. The position of the fourth state from the $(d_{3/2}^{-}f_{7/2})$ configuration is not known.

c. The (He^3,d), (He^3,α), (d,t), and (d,p) Reactions on Ca^{48}

J. R. Erskine, A. Marinov, and J. P. Schiffer

The $Ca^{48}(He^3,d)Sc^{49}$ reaction was studied[1] with 12.0-MeV He^3 particles from the Argonne tandem accelerator. The Sc^{49} nucleus is of particular interest. Since Ca^{48} forms a doubly closed shell, the level structure in Ca^{48} + p will be of considerable interest to theories of nuclear structure. Deuterons were analyzed in the magnetic spectrograph. The excitation energies, peak cross sections, and ℓ-value assignments were determined (Table III). The ground-state Q value was found to be 4.155 ± 0.015 MeV.

The energy levels of Ca^{49} were observed with the $Ca^{48}(d,p)Ca^{49}$ reaction. The results are in good agreement with those previously observed by Kashy. Some energy levels of Ca^{47} have been observed with both the (d,t) and the (He^3,α) reaction on Ca^{48}. A doublet has been observed at excitation energies of 2.584 and 2.608 MeV. One of these levels is presumably an $f_{7/2}$-hole state whereas the other one is probably a $d_{3/2}$-hole state.

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[1] J. R. Erskine, J. P. Schiffer, and A. Marinov, Bull. Am. Phys. Soc. 9, 80 (1964).

d. States in K^{46}, Sc^{51}, and Ca^{48} from Reactions on a Ca^{48} Target

A. Marinov and J. R. Erskine

A new isotope K^{46} has been produced with the $Ca^{48}(d,\alpha)K^{46}$ reaction.[1] The ground-state Q value in this reaction was measured to be 1.915 ± 0.015 MeV. Excited states were found at 586, 692, 890, and 1949 keV. These energy levels appear to be similar to those of Cl^{38}.

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[1] A. Marinov and J. R. Erskine, Phys. Letters 14, 46 (1965).

TABLE III. Sc^{49} energy levels observed in $Ca^{48}(He^3,d)Sc^{49}$.

Excitation energy (MeV)	ℓ	Peak cross section (mb/sr)
0	3	1.9
2.236		~0.08
2.387		~0.02
3.092	1	14.3
3.822	(3)	0.3
3.927		~0.03
4.007		~0.1
4.083	(3)	0.4
4.507	1	9.6
4.756	3	0.3
5.035	1	2.0
5.100	3	1.0
5.392	3	0.4
5.686	1	4.8
5.836	1	1.2
6.024		~0.07
6.210		~0.2
6.434		~0.2
6.555	(1)	0.5
6.742	(1)	0.6
6.836	(1)	1.7
6.903	(0)	0.2
7.044		0.1
7.081	(1)	1.5

This is expected since the low-lying levels should be accounted for with the same configuration as K^{46} except that the hole states are replaced with particle states.

Another new isotope Sc^{51} has been produced with the $Ca^{48}(\alpha, p)Sc^{51}$ reaction.[2] The ground-state Q value is -5.860 ± 0.020 MeV. Because of experimental difficulties, only the strongly populated levels in Sc^{51} could be seen. Four excited states were found at excitations of 0.860, 1.070, 2.330, and 3.020 ± 0.030 MeV. There is probably one more strong level at an excitation of 2.660 ± 0.050 MeV.

The excited states in Ca^{48} are being studied[3] by means of inelastic proton scattering. The fact that no levels were seen below 3.83 MeV excitation, in combination with the fact that Eklund and Bent[4] observed no pair emission from the decay of the 3.83-MeV state, shows that the spin of this state is not 0^+.

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[2] J. R. Erskine and A. Marinov, Bull. Am. Phys. Soc. 10, 479 (1965).

[3] A. Marinov and J. R. Erskine, Bull. Am. Phys. Soc. 10, 526 (1965).

[4] K. E. Eklund and R. D. Bent, Phys. Rev. 112, 966 (1958).

e. Isomeric State of Sc^{45}

J. L. Yntema and J. R. Erskine

The isomeric state, postulated[1] in Sc^{45} to interpret data on the $Ti^{46}(d, He^3)Sc^{45}$ reaction near the ground state, was isolated[2] with the help of the $Ti^{48}(p, \alpha)Sc^{45}$ reaction and the magnetic spectrograph. The state was found at 13 keV (see Fig. 16). This small excitation energy explains the difficulties experienced in attempts to locate this level from

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[1] J. L. Yntema and G. R. Satchler, Phys. Rev. 134, B976 (1964).

[2] J. L. Yntema and J. R. Erskine, Phys. Letters 12, 26 (1964).

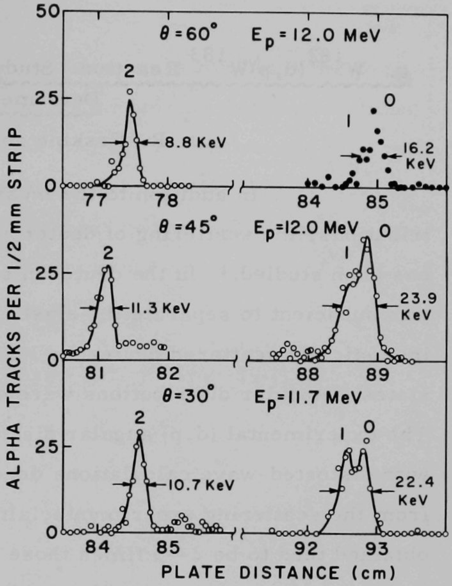

Fig. 16. Details of the ground-state doublet observed at 30°, 45°, and 60° together with the group corresponding to the excited state at 376 keV. The curves drawn through the points of the ground-state group were calculated by a computer program which unfolded this composite group. (From Ref. 2.)

measurements of gamma-ray lifetimes. Some candidates for additional $\frac{3}{2}^+$ levels were detected. In particular, it seems likely that a level close to the $\frac{1}{2}^+$ state may have some $d_{3/2}$ strength.

f. A Study of Energy Levels in Cd^{114} with the $Cd^{113}(d,p)Cd^{114}$ Reaction

R. K. Smither and J. R. Erskine

Data on the $Cd^{113}(d,p)Cd^{114}$ reaction are being used to interpret data taken with the $Cd^{113}(n,\gamma)Cd^{114}$ reaction at the Argonne CP-5 reactor. The bent-crystal spectrometer and a germanium-diode spectrometer have been used to record the gamma rays from transitions originating in the capture states and from those between the low-lying excited states. [More details about the (n,γ) reaction are given in Sec. I. A. 7.] We expect to be able to extract spectroscopic factors and assign ℓ values from our angular-distribution data with the help of DWBA theory.

g. $W^{182}(d,p)W^{183}$ Reaction: Study of a (d, p) Process on a Strongly Deformed Nucleus

J. R. Erskine and R. H. Siemssen

In addition to the measurement of the (d, p) angular distributions, the scattering of deuterons by W^{182} and of protons by W^{183} has been studied.[1] In the deuteron scattering experiment, the resolution was sufficient to separate the elastically scattered deuterons from the inelastically scattered deuterons leading to the first and second excited states. Angular distributions were obtained for both inelastic groups. The experimental (d, p) angular distributions are in reasonable agreement with distorted-wave calculations done with the optical parameters derived from the scattering experiments, although spectroscopic factors thus obtained tend to be 2—3 times those calculated from the unified model. A comparison of the inelastic scattering with the predictions of strong-coupling calculations in the adiabatic approximation[2] is planned.

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[1] R. H. Siemssen and J. R. Erskine, Bull. Am. Phys. Soc. 9, 664 (1964).

[2] R. C. Barrett, Nucl. Phys. 51, 27 (1964).

h. The Energy-Level Structure of W^{183}, W^{185}, and W^{187}

J. R. Erskine

The energy-level structure of W^{183}, W^{185}, and W^{187} has been studied by use of the (d, p) reaction.[1] The data have been interpreted with the single-particle rotational model which includes the effects of band mixing. The observed differential cross sections and excitation energies were compared with the predictions of this model. (See Fig. 17.) It was found that most of the low-lying excited

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[1] J. R. Erskine, Phys. Rev. 138, B66 (1965).

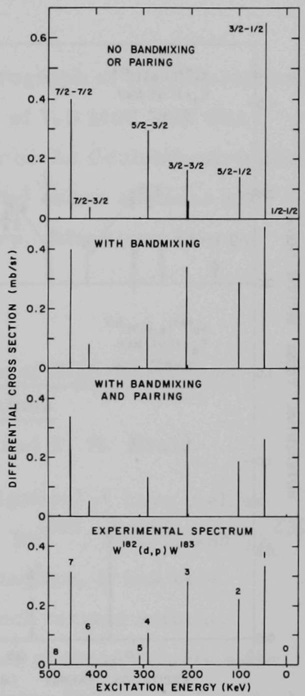

Fig. 17. Comparison of calculated and experimental spectra from the $W^{182}(d,p)W^{183}$ reaction at 60°. Theoretical spectra with and without band mixing as well as without the effects of pairing are shown. The states in one of the calculated spectra are labeled with the symbol J-K which specifies the total angular momentum J and its projection K on the symmetry axis. (From Ref. 1, Sec. h.)

states could be interpreted quite successfully with this model. Only three intrinsic states were needed. The rotational model used appears to be unable to interpret the energy levels observed at excitation energies above 500 keV—presumably because tungsten is near the upper limit of the region of permanent deformation.

i. The Energy Level Structure of Tl^{206}

J. R. Erskine

Details of the energy-level structure of Tl^{206} were observed by means of the $Tl^{205}(d,p)Tl^{206}$ reaction.[1] The high resolution used made it possible to observe levels that had been missed by

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[1] J. R. Erskine, Phys. Rev. 138, B851 (1965).

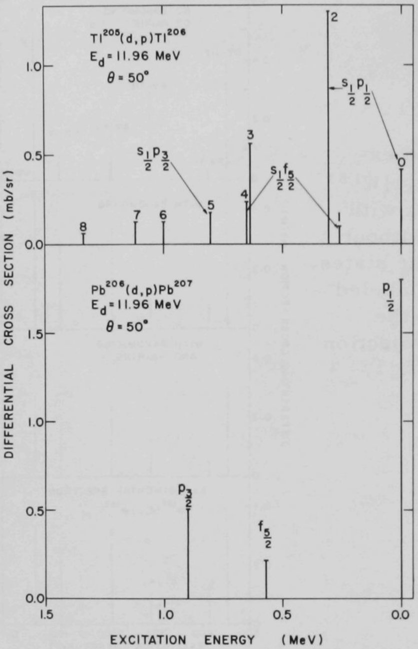

Fig. 18. A comparison of proton spectra from the $Tl^{205}(d,p)Tl^{206}$ and $Pb^{206}(d,p)Pb^{207}$ reactions taken at the same scattering angle and bombarding energy. The data are presented in the form of a bar graph in which the absolute differential cross sections of the reactions leading to the various excited states are plotted on an energy scale at the appropriate excitation energies. The levels are labeled with the configuration assignments discussed in the text.

earlier experimenters. Some angular-distribution data were obtained; these helped to identify the configurations of the levels. On the basis of the nuclear shell model, the low-lying energy levels of odd-odd Tl^{206} (which has a core of doubly magic Pb^{208}) are expected to be $s_{1/2}p_{1/2}$, $s_{1/2}f_{5/2}$, and $s_{1/2}p_{3/2}$ configurations. Fairly certain identifications of these configurations (Fig. 18) were made from the data. Knowledge of these levels, particularly the splittings of the doublets, is important if one is to learn the nature of the residual interaction between the odd nucleons in odd-odd nuclei near Pb^{208}.

j. A Study of the Energy Levels of Pb^{207}, Pb^{208}, and Pb^{209} with (d, p) Reactions

J. R. Erskine and H. S. Hans

The energy levels of Pb^{207}, Pb^{208}, and Pb^{209} have been studied with the (d, p) reaction at high resolution. Most of these data were taken with a multiple-gap magnetic spectrograph at the Massachusetts Institute of Technology at a bombarding energy of 7.5 MeV. At this bombarding energy, the reaction mechanism is of the Coulomb-stripping type. The absolute magnitudes of the differential cross sections are being compared with the results of DWBA theory. Many new energy levels have been observed.

k. A Study of Actinide Nuclei by Means of High-Resolution Charged-Particle Reactions

J. R. Erskine, A. M. Friedman,* and T. H. Braid

The initial phases of this investigation[1,2] have yielded (d,p) and (d,d') data on targets of U^{234}, U^{236}, Pu^{240}, Pu^{242}, and Th^{230}. Since many of these targets are intensely radioactive, it has been necessary to develop techniques for handling such targets without contaminating the magnetic spectrograph. Some of these targets were prepared by the isotope separator of the Chemistry Division. The (d,p) data are quite useful in identifying various intrinsic states in these nuclei as well as in exciting many energy levels previously unknown. In a (d,p) reaction, the rotational band associated with each intrinsic state has a particular signature; i.e., the relative differential cross sections of members of the rotational band are unique to that particular intrinsic state and stay more or less the same for neighboring nuclei. Excitation energies and interpretations of the levels (their spins and the intrinsic states from which they originate) have been made for Th^{231}, U^{235}, U^{237}, Pu^{241}, and Pu^{243}. The ground-state Q values for the (d,p) reactions which produced these nuclei are 2.923 ± 0.008, 3.065 ± 0.008,

*Chemistry Division.

[1] J. R. Erskine, A. M. Friedman, and T. H. Braid, Bull. Am. Phys. Soc. 10, 40 (1965).

[2] A. M. Friedman, J. R. Erskine, and T. H. Braid, Bull. Am. Phys. Soc. 10, 540 (1965).

2.896 ± 0.005, 3.014 ± 0.005, and 2.812 ± 0.008, respectively. In addition, the deformations of the target nuclei have been measured by performing Coulomb-excitation experiments. Work to obtain targets of U^{234}, Pu^{238}, Pu^{244}, Cm^{244}, Cm^{246}, and Cm^{248} is in progress. With the special techniques developed, it is hoped that radionuclides with half-lives as short as 100 years can be handled. A study of (d,t) reactions on these targets is beginning. Excellent data have been obtained which is proving to be of great help in recognizing the various intrinsic states.

ℓ. Automatic Plate-Scanning Machine

J. R. Erskine, R. H. Vonderohe,* and N. G. Sobel*

Considerable progress has been made in the development of an automatic plate-scanning machine. The Westinghouse image-dissector pickup tube (WX-30029) has been shown to have sufficient resolution and sensitivity to be able to scan nuclear track plates from the magnetic spectrograph. Signal-to-noise ratios of 10:1 have been easily obtained in scanning across 9-MeV proton tracks. The observed electrical signal from crossing a track has a full width at half maximum of approximately 5 microns in the plane of the emulsion. This is only 3 times the grain size of the emulsion. In time this width probably can be further reduced with a consequent increase in the signal-to-noise ratio. With this tube operating at the scanning rate now in use, the time to process a 1×25-cm strip of emulsion should be only approximately 15 min.

We are linking the scanning tube to a small digital computer (the PDP-7 computer manufactured by Digital Equipment Corporation of Maynard, Massachusetts) which will control the scanning and perform some of the pattern recognition needed to identify the nuclear tracks in the emulsion.

*Applied Mathematics Division.

m. Automatic Decomposition of Experimental Spectra from the Magnetic Spectrograph

J. R. Erskine and P. Spink

The rapid accumulation of data which is possible with a magnetic spectrograph makes it necessary to develop rapid means of interpreting these data. This will be particularly true when the automatic plate-scanning system becomes operative. A computer program being developed to be run on the CDC-3600 will automatically decompose the experimental spectra into individual line shapes. This program is intended to take any spectrum and, without human intervention, decompose it into the individual peaks. The only information fed the computer is the shape of a reference peak, which is in the form of a table of numbers. Part of the output is a plot (Fig. 19) of the experimental points and the computer's

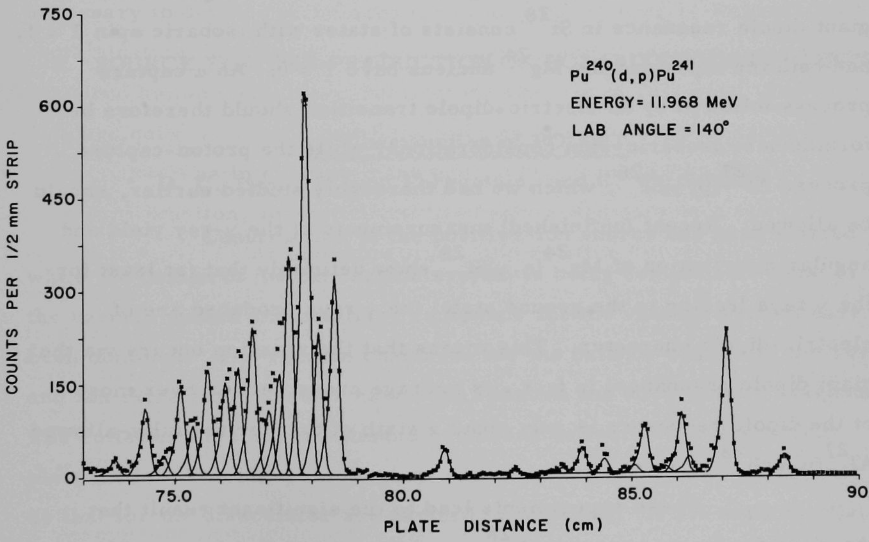

Fig. 19. Spectrum of protons observed at 140° from a Pu^{240} target bombarded with 11.96-MeV deuterons. (See Sec. I. C. 6. k.) The points are the raw data; the lines represent the best computer fit of the reference peak to the raw data.

attempt to fit these data to the shape of the reference peak. A version of this program which is now running requires initial guesses for the positions of the peaks. This program has considerably improved the accuracy with which excitation energies and peak areas can be extracted from the data as well as reducing the amount of human labor required to extract these numbers.

7. RADIATIVE-CAPTURE STUDIES OF THE GIANT DIPOLE RESONANCE

L. Meyer-Schützmeister, Ralph E. Segel, and Zeev Vager

We have recently extended our investigations of the giant dipole resonance through radiative proton capture by studying the reaction $Mg^{24}(\alpha, \gamma)Si^{28}$, induced by the Argonne 12-MeV tandem generator. The giant dipole resonance in Si^{28} consists of states with isobaric spin $T = 1$, and both the alpha and the Mg^{24} nucleus have $T = 0$. An α capture process followed by an electric-dipole transition should therefore be forbidden by isobaric-spin considerations, while the proton-capture process $Al^{27}(p, \gamma)Si^{28}$, which we had thoroughly studied earlier, should be allowed. Recent (unfinished) measurements of the γ-ray yield and angular distribution of $Mg^{24}(\alpha, \gamma)Si^{28}$ show definitely that (at least for the γ rays leading to the ground state) the γ rays produced are of electric-dipole character. This means that the reaction occurs via the giant dipole resonance; in fact, its average cross section over most of the dipole resonance is only about a sixth of that for the fully-allowed $Al^{27}(p, \gamma)Si^{28}$ process.

These experiments lead to the significant result that the giant dipole resonance in Si^{28} cannot be a pure $T=1$ state. Instead, Coulomb forces enable an originally $T=0$ state formed by α capture in Mg^{24} to become a $T=1$ state and make an electric-dipole γ-ray transition to the ground state. The transition probability depends, of course, on the presence and overlap of two states with isobaric spin T = 0 and T = 1; this probability usually is very small. The transitions take place in times of the order of 10^{-20} to 10^{-21} sec. Therefore, the relatively large yield of the $Mg^{24}(\alpha, \gamma)Si^{28}$ reaction going via the giant dipole resonance implies that this resonance is at least partially composed of compound-nuclear states which are sufficiently long-lived to enable Coulomb forces to mix the isobaric-spin states.

The (α, γ) reaction is now being studied in detail throughout the giant dipole resonance and the results will be carefully compared with the proton-capture process in the hope that this will yield further information on the reaction mechanism responsible for the giant dipole resonance.

8. SOURCE FOR THE PRODUCTION OF POLARIZED IONS (POLISO)

a. Construction of POLISO

D. C. Hess, D. von Ehrenstein, and C. W. Schmidt

Construction of the positive-ion source has been started while the design of the conversion system is being completed. Most of the vacuum pumps and auxiliary equipment for the vacuum system have been obtained. The vacuum chambers for the cathode chamber, ionizer, and ion extraction chamber have been finished and successfully evacuated. The coils for the ionizer solenoid have been delivered and some field plots made. The six-pole magnets and their vacuum chambers as well as that for the dissociator are partially completed. A 150-watt oscillator was constructed for preliminary tests of the dissociator. The transition units, Wien filter, adder (charge exchange), solenoid and other beam-handling components are being designed.

The various polarized-ion sources (more than a half dozen) in use or under construction in Europe were studied by a two-man team (DCH and DvE) during a one-month tour. The information obtained not only reinforced the basic design but indicated numerous valuable changes and refinements of a nature that could only be obtained from such actual contact with the work.

b. Proposal for a Source of Completely Polarized Deuterons

D. von Ehrenstein, D. C. Hess, and G. Clausnitzer*

A new procedure has been proposed[1] to obtain (theoretically) 100% population of any one of the three possible nuclear substates $m_D = 1, 0, -1$ with the high intensity that can be obtained by using multipole inhomogeneous magnets. Previous high-intensity machines had a theoretical upper limit of only 67% population in the desired deuteron orientation. The proposed new scheme (Fig. 20) uses an rf transition in the region between two six-pole separator magnets and another rf transition after the second six-pole magnet. The application of a second six-pole magnet after the first rf transition is the essential new feature of this proposal; it eliminates the unwanted deuteron substate which otherwise decreases the degree of polarization.

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*University of Erlangen, Germany.

[1] D. von Ehrenstein, D. C. Hess, and G. Clausnitzer, Bull. Am. Phys. Soc. 10, 55 (1965).

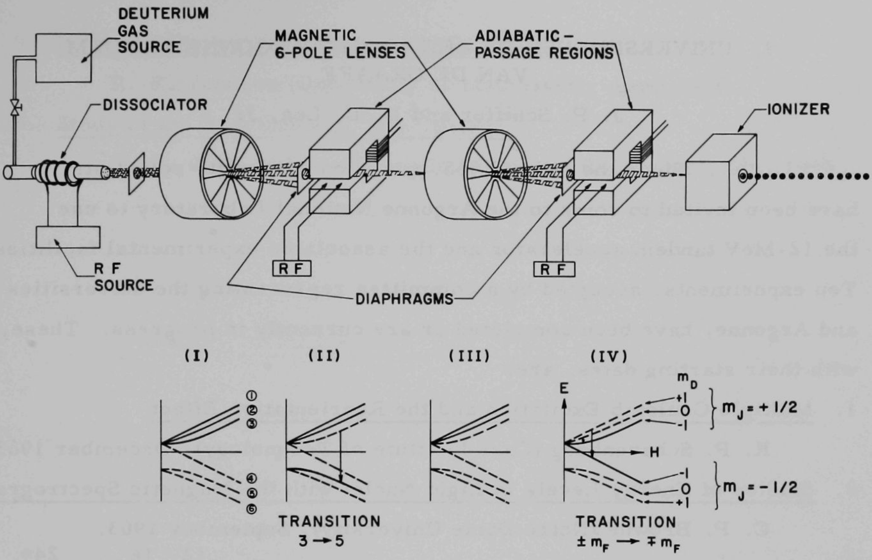

Fig. 20. Diagrams showing the main features of the proposed source and its principles of operation. Atoms with states $m_J = \frac{1}{2}$ are refocused by the first six-pole lens while those with $m_J = -\frac{1}{2}$ are diverted to the walls (and lost), as indicated in hyperfine plot (I). The first adiabatic passage induces the transition described as $3 \rightarrow 5$ in plot (II). State 5 has $m_J = -\frac{1}{2}$; so it is removed by the second six-pole lens and only states 1 and 2, represented by the solid curves in plot (III), are left. A weak-field adiabatic-passage transition interchanges the m_F's, state 1 ($m_F = m_J + m_D = +\frac{3}{2}$) changing to state 4 ($m_F = -\frac{3}{2}$) and state 2 ($m_F = \frac{1}{2}$) changing to state 3 ($m_F = -\frac{1}{2}$) as indicated in plot (IV). In a strong magnetic field both of these states will have $m_D = -1$ so theoretically there is 100% population having this nuclear orientation. Ionization in a strong magnetic field gives deuterium ions with vector polarization $P_3 = -1$ and tensor polarization $P_{33} = +1$. The direction of the magnetic field in the ionizer is the reference axis. This is only one of several possible combinations of transitions by which different vector and tensor polarizations may be obtained [D. von Ehrenstein, D. C. Hess, and G. Clausnitzer (to be published)]. For general reference and the terminology, see the recent review article by J. M. Dickson in Polarized Ion Sources and the Acceleration of Polarized Beams, edited by F. J. M. Farley (North-Holland Publishing Company, Amsterdam, 1965), Vol. I.

9. UNIVERSITY USE OF THE 12-MEV ARGONNE TANDEM VAN DE GRAAFF

J. P. Schiffer and L. L. Lee, Jr.

Since the fall of 1963, qualified university scientists have been invited to come to the Argonne National Laboratory to use the 12-MeV tandem accelerator and the associated experimental facilities. Ten experiments, accepted by a committee representing the universities and Argonne, have been completed or are currently in progress. These, with their starting dates, are:

1. <u>Multiple Coulomb Excitation and the Reorientation Effect</u>

   R. P. Scharenberg (Case Institute of Technology), December 1963.

2. <u>Studies of Energy Levels in Light Nuclei with the Magnetic Spectrograph</u>

   C. P. Browne (Notre Dame University), September 1963.

3. <u>Alpha-Gamma Correlation Studies of the Reaction $C^{12}(O^{16}, \alpha)Mg^{24*}$</u>

   W. W. Eidson, J. G. Cramer, Jr., and R. D. Bent (Indiana University), August 1964.

4. <u>Magnetic Spectrograph Studies of the Reactions (He^{3}, α) and (He^{3}, d)</u>

   W. P. Alford, L. M. Blau, D. Cline, and J. J. Schwartz (University of Rochester), May 1964.

5. <u>Study of Reaction Cross Sections with Alpha Particles</u>

   L. Haskin (University of Wisconsin), December 1964.

6. <u>Short Nuclear Lifetimes by Doppler-Shift Techniques</u>

   R. D. Bent and P. P. Singh (Indiana University), November 1964.

7. <u>Investigation of Ca^{49} Isobaric-Analog States in Sc^{49}</u>

   K. W. Jones (Brookhaven National Laboratory), September 1964.

8. <u>(d,p) Reactions on Au and Cd</u>

   C. K. Bockelman, P. D. Barnes, and K. J. Wetzel (Yale University), July 1964.

9. Inelastic Proton Scattering from Cu and Zn

R. R. Johnson (University of Minnesota), April 1965.

10. Study of the Reaction $Ca^{40}(He^{3}, p\gamma)Sc^{42}$

H. E. Gove and D. Cline (University of Rochester), May 1965.

D. RESEARCH AT THE 60-IN. CYCLOTRON

The 60-in. cyclotron is one of the low-energy accelerators operated by the Chemistry Division. It accelerates α particles to 43.2 MeV, He^3 to 33 MeV, deuterons to 21.6 MeV, and protons to 10.8 MeV. For all four of these projectiles, it can produce external beams at the shutter in excess of 0.1 mA. In addition, it accelerates Li^6 to an energy of 66 MeV with usable external beams of the order of 0.01 μA.

The beam-handling equipment currently consists of a beam squeezer, three sets of quadrupole lenses, and two sets of left-right and up-down deflection magnets. A switching magnet permits the use of five different experimental stations. The energy of the incident particles can be lowered by use of a remotely-controlled foil changer at the focal point of the first set of quadrupole lenses.

Now that a second experimental area has been built, it has become feasible to install a beam-analyzing magnet system. It is anticipated that this system will be ready in the fall of 1965. The analyzer will provide a resolution width of 0.1% or less.

The cyclotron is in operation approximately 80 hours per week. On the average, the Physics Division uses 25 to 30% of the time.

1. THE 60-IN. SCATTERING CHAMBER AT THE CYCLOTRON

The scattering chamber will be moved to experimental area No. 2 at the cyclotron when a beam of magnetically analyzed particles becomes available, probably in the summer of 1965.

a. Nucleon-Capture Reactions

J. L. Yntema

The data on the $Zr^{90}(d,He^3)Y^{89}$ reaction have been interpreted[1] with the aid of the $Y^{89}(d,He^3)Sr^{88}$ reaction and DWBA calculations. The resultant ground-state configuration for Zr^{90} is

[1] J. L. Yntema, Phys. Letters 11, 140 (1964).

in good agreement with theoretical predictions. The (d,t) reactions on $Ca^{42,43,44,46,48}$ and the (d,He^3) reactions on $Ca^{42,43,44}$ are being analyzed. It is quite clear that the excited state near 2.6 MeV in Ca^{47} really consists of two levels, namely the $\frac{1}{2}^+$ and $\frac{3}{2}^+$ levels.

b. Scattering of 45-MeV Alpha Particles by Pb^{208}

G. R. Satchler,* H. W. Broek, and J. L. Yntema

The analysis of the data shows that the DWBA calculations permit a successful interpretation if the effects of Coulomb excitation are taken into account. In particular, the interference between Coulomb excitation and inelastic scattering predicts a dip in the cross section near 25°, the magnitude of the dip being about 10% of the cross section predicted without taking Coulomb excitation into account. This dip has been confirmed experimentally. Perhaps the effects due to Coulomb excitation for higher 3^- states are overestimated in the calculations so that it will be necessary to postulate a different deformability for the charge distribution and the optical potential.

*Oak Ridge National Laboratory.

c. Shell-Model Selection Rules and Excitation of 4^+ States in the $Ti(\alpha, \alpha')$ Reaction

G. R. Satchler,* J. L. Yntema, and H. W. Broek

The analysis of the excitation of the first 4^+ states in the even-even Ti isotopes shows that the vibrational model gives quite incorrect predictions for Ti^{48} and Ti^{50}. The results[1] are in good

*Oak Ridge National Laboratory.

[1] G. R. Satchler, J. L. Yntema, and H. W. Broek, Phys. Letters 12, 55 (1964).

agreement with predictions based on the shell-model wave functions of Bayman *et al*. For Ti^{46} the two predictions are practically identical.

d. Collective Excitations in the Zirconium Isotopes

H. W. Broek and J. L. Yntema

The angular distributions for alpha particles inelastically scattered by Zr^{90}, Zr^{91}, Zr^{92}, and Zr^{94} were measured and analyzed.[1] It was found that the systematics of preferentially excited states observed in the Ni-Zn region does not persist in the Zr region.

[1] H. W. Broek and J. L. Yntema, Phys. Rev. 138, B334-B339 (1965).

e. Wide-Angle Scattering of 43-MeV Alpha Particles by Ni^{58}

H. W. Broek, J. L. Yntema, B. Buck,* and G. R. Satchler*

Instead of obtaining angular distributions only to about 70°, the experimental range was extended to 160°. The oscillation period of both elastic and inelastic scattering (about 9° for the range usually covered) was found to increase substantially with increasing angle. The coupled-channel analysis showed that good agreement with the experiment can be obtained by using an optical-model potential whose absorptive part does not have the same shape as the real part.[1]

*Oak Ridge National Laboratory.

[1] H. W. Broek, J. L. Yntema, B. Buck, and G. R. Satchler, Nucl. Phys. 64, 259 (1965).

f. Angular Distributions of the $Mg^{25}(He^{3}, \alpha)$ Reaction

C. Mayer-Böricke and D. Dehnhard

Differential cross sections of the neutron pickup reaction $Mg^{25}(He^{3}, \alpha)$ have been measured between 10° and 90° at an incident

TABLE IV. Relative reduced widths for neutron pickup from Mg^{25}.

Energy of state in Mg^{24} (MeV)	J^{π}	$\frac{S}{S_g}$ (theor.)	$\frac{\Theta^2}{\Theta_g^2}$ (d,t)[a]	$\frac{\Theta^2}{\Theta_g^2}$ (p,d)[b]	$\frac{S}{S_g}$ (He^3,α)
0.0	0^+	1.0	1.0	1.0	1.0
1.368	2^+	$\frac{25}{14} = 1.8$	2.0	2.7	1.75 ± 0.2
4.12	4^+	$\frac{3}{14} = 0.21$	0.33	1.0	0.28 ± 0.1

[a] E. W. Hamburger and A. G. Blair, Phys. Rev. 119, 777 (1960).

[b] E. F. Bennet, thesis, Princeton University, 1958.

energy of 33 MeV. The angular distributions of the ground-state group and the first-excited-state group are of the same shape within experimental errors. While the ground-state transition can proceed only by pickup of an ℓ=2, j=5/2 neutron, the transition to the first excited state of Mg^{24} could show mixtures of ℓ = 0 and ℓ = 2 if only angular momentum conservation is taken into account. However, it seems that ℓ=0 admixtures can be neglected and that a pure ℓ=2, j=5/2 capture takes place. In confirmation of previous results on the (p,d) and (d,t) reactions,[1] this shows that the K selection rule governs the transition to the levels of the ground-state rotational band in Mg^{24}. Spectroscopic factors extracted by DWBA calculations were found to be in good agreement with the predictions of the rotational model, as seen in Table IV.

[1] M. H. Macfarlane and J. B. French, Rev. Mod. Phys. 32, 567 (1960).

2. STUDIES OF PICKUP REACTIONS

T. H. Braid and B. Zeidman

The study of (d, He^3) reactions on nuclei with both protons and neutrons in the $1f_{7/2}$ shell (Sc^{45}, V^{51}, Cr^{52}, and Fe^{54}) has shown that even at the beginning of the shell there is an admixture of $2p_{3/2}$ protons in the ground-state wave functions of the target nuclei. The strong peaks in the various spectra are due to $1f_{7/2}$ pickups for the low levels and 2s and 1d pickups for levels lying higher in the spectra. Even for Sc^{45}, however, the transition to the 2^+ level of Ca^{44} shows about 5% admixture of $2p_{3/2}$. In $V^{51}(d, He^3)Ti^{50}$, the spectroscopic factors for the $\ell = 3$ transitions to the 0^+, 2^+, 4^+, and 6^+ states are in good agreement with the prediction for pickup from a $(1f_{7/2})^3$ proton configuration but both the 2^+ and 4^+ states show $\ell = 1$ admixture. For Fe^{54}, an $\ell = 1$ peak is observed at approximately 1.3 MeV excitation in Mn^{53}. The nuclei in which only the protons are in the $1f_{7/2}$ orbital (isotopes of Mn, Fe, and Ni) are now being studied.

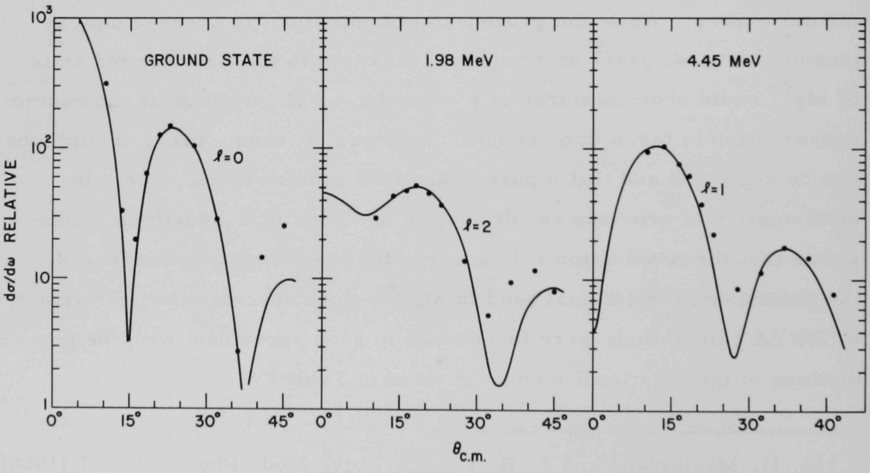

Fig. 21. Angular distributions for the $F^{19}(d, He^3)O^{18}$ reaction leading to the ground state, 1.98-MeV level, and 4.45-MeV level. The solid curves are from DWBA calculations with the TSALLY code.

There has recently been some question about the parity of the state at 4.45 MeV in O^{18}. The measured angular distributions for $F^{19}(d,He^3)O^{18}$ have been compared[1] (Fig. 21) with theoretical predictions. The data for the 4.45-MeV state fit only the prediction for $\ell = 1$, and thus require negative parity. In the light of other evidence, the results clearly assign a spin and parity of 1^-, in agreement with a recent theoretical analysis.

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[1] B. Zeidman and T. H. Braid, Phys. Letters 16, 139 (1965).

3. He^3 SCATTERING FROM THE EVEN-A Ni ISOTOPES

T. H. Braid, D. Dehnhard, R. H. Siemssen, and B. Zeidman

The nuclear symmetry term in the optical potential for elastic scattering has so far been established only for nucleons. It is therefore desirable to determine this term for He^3 scattering. For this purpose we have measured the elastic scattering of He^3 from the even-A Ni isotopes Ni^{58}, Ni^{60}, Ni^{62}, and Ni^{64} in the angular range from 25° to 90°. An analysis of the data in terms of the optical model (Fig. 22) shows some evidence for a (N - Z) dependence. As a by-product, the angular distributions of the collectively enhanced inelastic scattering to the first excited 2^+ state and to the 3^- state at approximately 5 MeV excitation were obtained. The angular distributions for inelastic scattering follow the Blair phase rule.

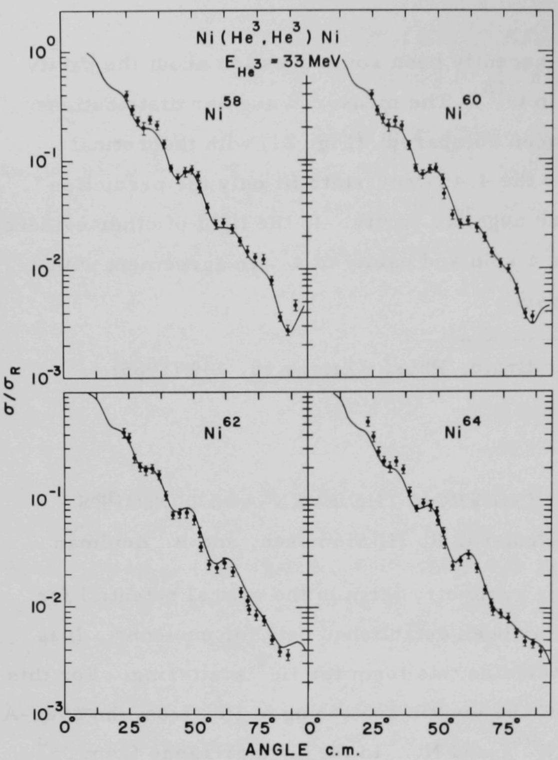

Fig. 22. Comparison of measured differential cross sections with angular distributions obtained from an optical-model search calculation of the elastic scattering of 33-MeV He^3 on the even-A Ni isotopes.

4. DELAYED PROTON EMISSION

T. H. Braid, R. W. Fink,* and A. M. Friedman†

Our earlier measurements were made with the 66-MeV Li^6 beam from the 60-in. cyclotron. Since the available intensity of these particles was very low, it was not possible to obtain definite results. In September 1964 a good beam of 33-MeV He^3 particles became available

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†Chemistry Division.

and the work has been very much more productive. The $(He^3, 2n)$ reaction has been used to produce a number of proton-rich isotopes of light nuclei whose positron decay feeds excited levels which are unstable against emission of protons. The resulting "positron-delayed" proton radioactivity shows a half-life which is that of the parent positron activity. In our experiments, a mechanical arrangement chopped the external beam at regular intervals and moved the target over to a semiconductor detector. The half-life and the energy spectrum of the protons were recorded in a time interval from 0.02 to 1 sec after the end of the beam burst. The measurements[1] show that the positron decay of Ne^{17} has a half-life of 107 ± 5 msec and that it is followed by proton groups having energies of 3.9, 4.80, 5.3, and 7.03 MeV. For S^{29} the values are $T_{1/2}$ = 180 ± 10 msec and E_p = 5.5 ± 0.08 MeV and for A^{33} the resolved groups have E_p = 4.5 and 6 MeV. For Ne^{17} and S^{29}, most of the groups agree with similar measurements made elsewhere. Since the levels must correspond to allowed or superallowed β transitions, the energies and intensities of the proton groups give information on the spin, parity, and isotopic spin of the corresponding levels.

The major experimental difficulty is a strong background due to positrons, particularly below 3 MeV. A superconductor magnet is being built to provide a strong field to prevent the positrons from striking the detector.

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[1] T. H. Braid, A. M. Friedman, and R. W. Fink, Bull. Am. Phys. Soc. 10, 120 (1965).

E. DEVELOPMENT OF THE VARIABLE-ENERGY CYCLOTRON HIVEC

R. Benaroya,* K. W. Johnson,* T. K. Khoe,** J. J. Livingood, H. P. Mogensen,*** and W. J. Ramler*

The proposed HIVEC is a sector-focused cyclotron with a diameter larger than those of any existing machines of this type. As a result, a given projectile energy can be attained without going to such highly charged ions as are required in smaller cyclotrons. The consequence is a great increase in output current since ion sources produce low-charge ions in greater numbers than high-charge ions.

Table V gives the maximum energy that each of several projectiles can reach in the largest existing cyclotron, the charge state that must be employed to reach it, the charge state that would be required

TABLE V. Comparison between the HIVEC and existing machines.

Projectile	Max. energy from other machine (MeV)	Charge state HIVEC	Charge state Other	Yield from HIVEC / Yield from other
C	168	2^+	4^+	46
N	217	3^+	5^+	350
O	192	3^+	5^+	700
Ne	156	3^+	5^+	440
A	200	4^+	8^+	185

*Chemistry Division.

**Particle Accelerator Division

***Institute of Nuclear Science and Engineering, ANL.

TABLE VI. Maximum ion energies and beam intensities for the HIVEC.

Ion	HIVEC max. energy (MeV)	Number of external ions/sec (units of 10^{12})
H^{+}	120—150	630
D^{+}	120	630
He^{2+}	240	315
$N^{2+} \cdots N^{5+}$	134 · · · 600	520 · · · 1
$O^{2+} \cdots O^{5+}$	118 · · · 600	370 · · · 0.3
$C^{2+} \cdots C^{4+}$	162 · · · 480	208 · · · 6
$Ne^{2+} \cdots Ne^{5+}$	98 · · · 600	310 · · · 0.3
$A^{3+} \cdots A^{8+}$	108 · · · 760	280 · · · 0.3

to reach the same energy in the HIVEC, and the ratio of the number of output particles per second from the HIVEC to that from the other machine. For the higher energies of which the HIVEC is capable, the ratio of yields is (of course) infinite.

On an absolute basis, the maximum energies and the yields of external particles per second are as shown in Table VI.

The major parameters of the HIVEC are as follows.

Magnet:

170-inch diameter, 2000 tons of iron

3 sectors, 60° maximum spiral angle

Hill gap = 15.1 inches

Valley gap = 23.5 inches

$\overline{B}_{max}$ = 16.7 kilogauss

$\overline{B}_{min}$ = 3.3 kilogauss

Final orbit radius = 75 inches

Total power $\approx$ 1 megawatt

Dee:

Single, 180°

Driven to 150 kV

Frequency range = 4.2—12.7 Mc/sec

Total power = 1.4 megawatts

The proposed accelerator is an enlarged version of successfully operating machines. Anticipated currents are based on demonstrated ion-source capabilities, and very conservative factors have been used in calculating ion survival to the outside world. It is planned for flexibility in producing large currents of light and heavy ions with precise energy control and resolution. It will be an incomparable tool for problems of nuclear structure, solid-state studies, and for isotope production, particularly in the transuranic region.

A model dee has been tested successfully and studies with a model magnet are being pursued.

F. OTHER NUCLEAR EXPERIMENTS

Several experimental nuclear investigations in the Physics Division are not closely associated with any of the major sources of neutrons or charged particles. These independent studies are collected for convenience in this section.

1. DECAY SCHEMES OF RADIONUCLIDES

a. Internal-Conversion-Electron Spectrometer with a Superconducting Solenoid

S. B. Burson, T. Gedayloo, and E. B. Shera

Most previous studies of the gamma-ray spectra associated with thermal-neutron capture have yielded only the energies and intensities of the transitions. To aid in the interpretation of these extremely complex capture gamma-ray spectra, an apparatus is being constructed to measure the internal-conversion coefficients of some of the transitions. This will make possible definite spin and parity assignments to many of the states populated by the capture-gamma cascade. In particular, it will facilitate the study of many odd-odd nuclei that are difficult to obtain through radioactive decay processes.

The superconducting solenoid producing the longitudinal magnetic field in this instrument is 10 in. long and has an inside diameter of 2 in. In preliminary tests, it produced a field of 26 000 gauss. A target, mounted 1.5 in. below one end of this solenoid, will be irradiated by a beam of thermal neutrons passing horizontally through an evacuated target chamber. The intense magnetic field will focus the resulting internal-conversion electrons onto a Si detector placed near the opposite end of the solenoid. (This focusing is intended to enhance the electron lines relative to the intense background of gamma rays from the target.)

A gamma-ray detector located directly below the target will permit coincidence studies. The instrument should be completed early in the summer of 1965.

b. Excited States of Xe^{129}

S. B. Burson and E. B. Shera

A study of the excited states of Xe^{129} populated in the decay of Cs^{129} has been completed. Six excited states were observed; their energies and the spins and parities assigned are: 40 keV, $\frac{1}{2}^+$; 235 keV, $\frac{11}{2}^-$; 321 keV, $(\frac{1}{2}^+, \frac{3}{2}^+)$; 416 keV, $(\frac{1}{2}^+, \frac{3}{2}^+)$; 591 keV, $(\frac{1}{2}^+, \frac{3}{2}^+)$; 945 keV, $(\frac{1}{2}^+, \frac{3}{2}^+)$. Five of these can be identified with levels predicted by the recent pairing-model calculations of Kisslinger and Sorensen. No evidence for a sixth spin-$\frac{5}{2}$ state was found. The $\frac{11}{2}^-$ state at 235 keV is the previously-known isomeric level.

2. LEVELS POPULATED BY BETA DECAY

H. H. Bolotin

The activities studied were produced at the research reactor CP-5 and at the 60-in. cyclotron. A versatile counting system, in which eight digital coincidence gates were employed in conjunction with an 800-channel pulse-height analyzer, was used to advantage in all of the gamma-gamma coincidence studies described. The recently acquired Li-drifted Ge-diode gamma-ray detector (full width at half maximum: 3.2 keV at 1.33 MeV) provides the high resolution required for nuclides in which the gamma-ray spectra are too complex for the relatively limited energy resolution of NaI detectors.

a. Level Structure of Sn^{116} As a Test of Pairing-Force Calculations

In the last several years, the use of a pairing interaction in short-range residual nuclear-force calculations has increased the interest in, and need for, detailed experimental investigations of the excited states of nuclei that have singly-closed shells, especially the tin isotopes. The even-A tin isotopes that provide the most significant comparison with theory are Sn^{116}, Sn^{118}, and Sn^{120} because only they have been found to have more than two excited states populated by the beta decay of the In or Sb parent isotopes.

(i) States Populated by the Decay of 1-hour Sb^{116}. The excitation energies, spins and parities of the observed levels are 2.90 MeV, 7^-; 2.76 MeV, 6^-; 2.35 MeV, 5^-; 2.25 MeV, 3^-; and 1.29 MeV, 2^+. The observed transitions and their multipole orders are $7^- \rightarrow 6^-$, M1; $6^- \rightarrow 5^-$, E2; $5^- \rightarrow 2^+$, E3; and $2^+ \rightarrow 0^+$, E2. In addition, a strong 0.545-MeV E2 transition (7^- to 5^-), previously unreported, was observed. The assignments of spin and multipole order were determined from angular-correlation and internal-conversion measurements.[1] All beta decay was found to proceed exclusively to the 7^- level. The half-life of the 5^- (2.35-MeV) state was determined to be $(2.3 \pm 0.2) \times 10^{-7}$ sec by use of delayed-coincidence techniques. The 7^- level at 2.90 MeV, previously reported to have a half-life greater than 10^{-7} sec, was found to be prompt ($t_{1/2} < 2 \times 10^{-9}$ sec). Triple-coincidence measurements determined a positron-to-capture ratio of 0.237 ± 0.011, from which the transition energy was inferred to be 2.11 ± 0.03 MeV. A complete systematic summary, determined experimentally, for Sn^{116}, Sn^{118}, and Sn^{120}, as populated by the corresponding Sb isotopes, were compared with the latest detailed pairing-force calculations (Fig. 23). These comparisons indicate that the theory provides a highly satisfactory account of the experimental data. In addition, the experimentally determined reduced transition probabilities in each of these nuclides are compared with the predictions of this theory.

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[1] H. H. Bolotin, Phys. Rev. 136, B1566 (1964).

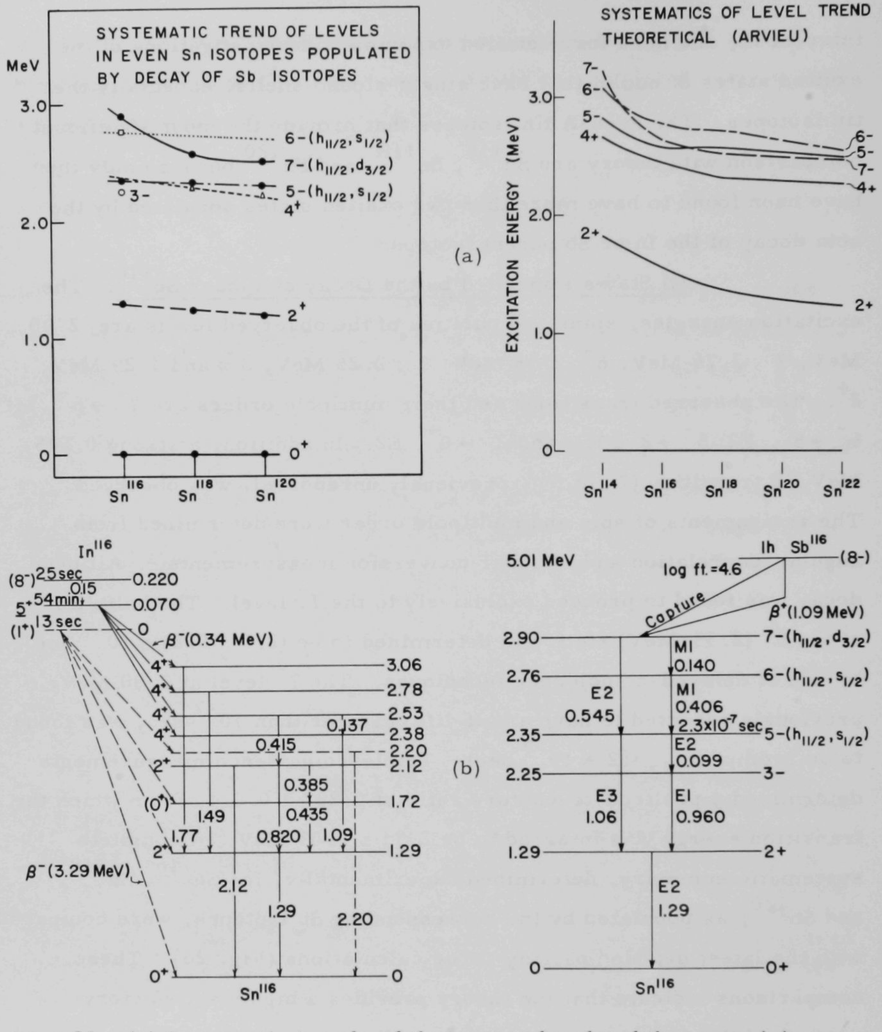

Fig. 23. (a) Systematic trends of the energy levels of the even-A isotopes of Sn: left, experimental; right, theoretical [R. Avieu, thesis, L'Universite de Paris, Institut du Radium, 1962 (unpublished)]. (b) Proposed decay schemes of Sn^{116}. Left: Transitions following the decay of 54-min In^{116}. The dashed lines show the pertinent features of the decay scheme of 13-sec In^{116} [P. Fettweis and J. Vervier, Phys. Letters 3, 36 (1962)]. Right: Transitions following the decay of 1-hour Sb^{116}. All energies are in MeV.

(ii) Levels Populated by the Decay of 54-min In^{116m}.

This decay was reinvestigated[2] by means of scintillation singles and coincidence spectroscopy techniques. Angular-correlation measurements of four pairs of successive gamma rays served as the basis of the assignment of the spin and parity of all levels, and the multipole order of all transitions. The excitation energies (in MeV, relative to the 0^+ ground state) and characters (j^π) of the observed levels were 3.06 (4^+), 2.78 (4^+), 2.53 (4^+), 2.12 (2^+), 1.72 (0^+), and 1.29 (2^+). In addition, two new transitions with energies of 0.385 and 0.435 MeV (previously unreported in this decay) were observed to feed and depopulate, respectively, the level at 1.72 MeV. The relative intensities of all transitions were obtained. The experimental results were compared with the previously reported work and were discussed in the light of recent pairing-force calculations. All levels populated in this decay, with the exception of the 1.29-MeV first excited state, were found to be distinctly different from those populated in the same nuclide by the decay of 1-hour Sb^{116}. These findings were discussed, and arguments were presented to account for these differences.

[2] H. H. Bolotin, Phys. Rev. 136, B1557 (1964).

b. Ga^{66} Levels Populated by the Decay of 2.4-hour Ge^{66}

This investigation has been continued and extended with the aid of a Li-drifted Ge-diode detector whose full width at half maximum is 3.2 keV at 1.33 MeV. The use of this high-resolution detector was felt to be necessary when intensive studies using NaI detectors failed to provide an internally consistent decay scheme and assignments of level parameters. These scintillation studies were sufficiently successful to reveal certain ambiguities and internal inconsistencies present in the decay schemes previously reported by other groups and to allow determination of the lifetime of the previously unreported first excited state at 0.046 MeV (21 ± 2 nsec). However, it became apparent that the spectra were too complex for the restricted resolution capabilities of NaI. Initial Ge-detector spectra revealed much of the source of these difficulties. The prominent "0.185-MeV" gamma ray was found to consist of two equally intense transitions at 0.182 and 0.189 MeV, and several previously unreported transitions of moderate strength have been observed. These studies have also fully resolved other prominent transitions in the energy range between 250 and 550 keV, which were not resolved in the scintillation studies. Coincidence studies which employ solid-state detectors are in progress in order to attempt to determine an unambiguous decay scheme and to facilitate assignment of level parameters.

c. Ga^{69} States Populated by the Decay of 40-hour Ge^{69}

Although work on this odd-Z/even-N nuclide was initiated because the Ge^{69} activity was a contaminant in the Ge^{66} source for the work in Sec. I. F. 2. b, it is being continued because of several interesting aspects of the level structure of Ga^{69}. The investigation employs Li-drifted Ge detectors because the decay of this nuclide is too complex to be successfully studied with scintillators. Some of the discrepancies in earlier scintillator studies have already been resolved, but other spectral complexities require further coincidence studies with Ge detectors. Measurements to determine internal-conversion coefficients are also planned. (For other work on the Ga isotopes, see Secs. I. F. 2. b and I. A. 4. c.)

3. MUONIC X RAYS

S. Raboy, R. E. Coté, C. C. Trail, J. Bjorkland,* V. L. Telegdi,† R. Ehrlich,† and R. Powers†

The study of muonic x rays in the deformed region shows hyperfine splitting induced by the interaction between the quadrupole moment of the nucleus and the muon in its orbit. The interaction as treated by Jacobsohn[1] and independently by Wilets[2] consists of a static and dynamic part, i.e., the muon interacts with the static quadrupole moment of the nucleus and in addition induces transitions between the nucleon states by a strong quadrupole transition probability. This is true for nuclei with large deformations and with low-lying levels. In particular, if the nucleus can be described by the rotational model then the static quadrupole moments and the transition quadrupole moments depend on one parameter, the intrinsic quadrupole moment. In nuclei with ground-state spin equal to zero or $\frac{1}{2}$ the analysis of the hyperfine splitting will determine the sign and magnitude of the intrinsic quadrupole moment, which up to now has not been accessible by any other experimental technique.

The experimental arrangement (Fig. 24) makes use of the muon channel at the University of Chicago synchrocyclotron. The particle beam was composed of muons, pions, and electrons in the proportions of about 2:2:1. The beam underwent momentum selection at approximately 150 MeV/c by a wedge magnet and was collimated to a $7\frac{1}{2} \times 7\frac{1}{2}$-in. area by a Pb wall 2 ft thick. This beam delivers about

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†University of Chicago.

[1] B. A. Jacobsohn, Phys. Rev. 96, 1367 (1954).

[2] L. Wilets, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 29, 1 (1954).

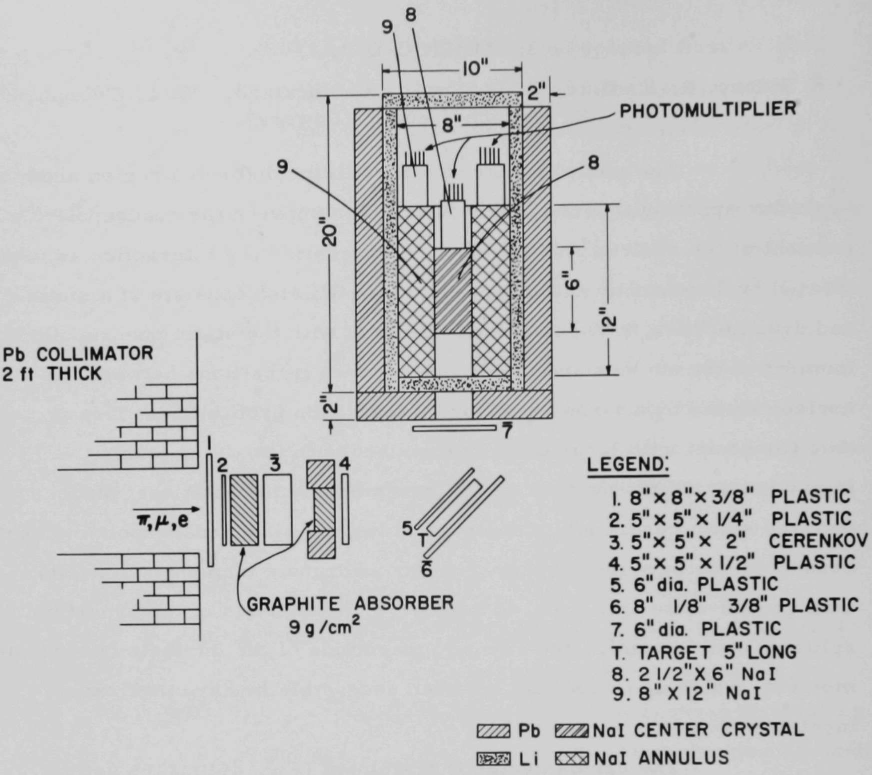

Fig. 24. Physical arrangement of apparatus for measurement of muonic x rays. An x-ray event which is to be analyzed is identified by coincidence (245$\overline{367}$; 8$\overline{9}$). A calibration event consists of coincidence (8$\overline{9}$; $\overline{157}$). Counter 8 is the center crystal of the NaI anticoincidence spectrometer.

10 000 muons/sec in this area. About 5000 muons/sec stopped in the targets used in this experiment. The absorption of a muon in the target was identified by the proper combination of coincidences and anticoincidences in a system of seven counters; and the resulting muonic x rays were detected by a shielded scintillation spectrometer with an anticoincidence annulus.[3] The spectrometer was gated by a "μ stop" pulse from the identification system.

[3] C. C. Trail and S. Raboy, Rev. Sci. Instr. 30, 425 (1959).

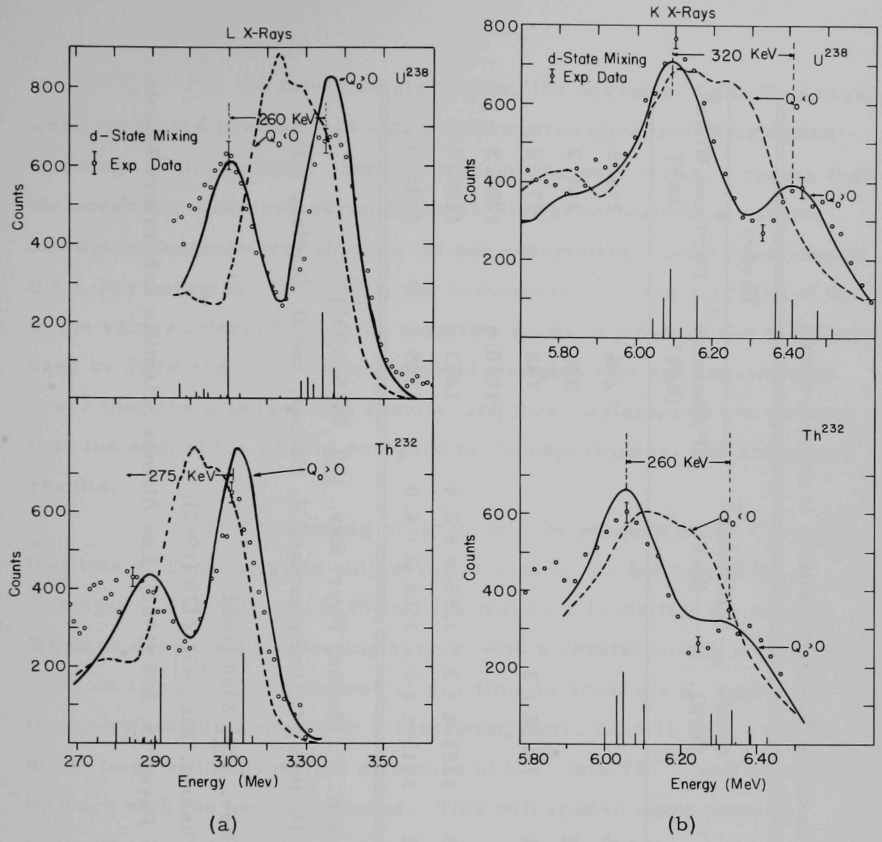

Fig. 25. Observed and theoretically predicted muonic x-ray spectra for U^{238} and Th^{232}: (a) L x rays, (b) K x rays. The open circles are experimental data (corrected for capture gammas, accidentals, etc.). The vertical bars at the bottom of the graph show the theoretical spectra for $Q_0 > 0$. The solid curve, to be compared with experiment, was obtained by folding the spectrometer resolution into that spectrum. The broken curve is the analogous prediction for $Q_0 < 0$. The observed "apparent" fine-structure splittings are indicated.

The results (Fig. 25) for the K and L x rays of U^{238} and Th^{232} show that the intrinsic quadrupole moment of both nuclei is positive and that for the resolution of the instrument the one-parameter fit is adequate. It appears therefore that the rotational model of strongly deformed nuclei is applicable to these nuclei.

TABLE VII. Energies of the 2p→1s transitions in muonic atoms.

Element	This exp. (keV)	Chicago[a] (keV)	Cern[b] (keV)	Columbia[c] (keV)	Theory	
					Pustovalov[d] (keV)	Ford and Wills[e] (keV)
Mg	296.2 ± 0.5	295.6 ± 1.6			296	294.3
Al	346.1 ± 0.9	345.7 ± 1.2			346	344.2
Ca	780.7 ± 0.8	790.8 ± 1.6	782.8 ± 3		782	771.8
V	1011.3 ± 2.3				1010.5	1000.3
Fe	1254.5 ± 4.0	1262.0 ± 2.5	1255.4 ± 3	1255.4 ± 2.4	1253	1237.7
Cu	1511.4 ± 1.0	1511.0 ± 5.5	1515.1 ± 6	1508.2 ± 4.0	1509	1496.0

[a] H. L. Anderson, C. S. Johnson, and E. P. Hincks, Phys. Rev. 130, 2468 (1963).

[b] D. Quitman, R. Engfer, U. Hegel, P. Brix, G. Bachenstoss, K. Goebel, and B. Stadler, Nucl. Phys. 51, 609 (1964).

[c] W. Frati and J. Rainwater, Phys. Rev. 128, 2360 (1962).

[d] G. E. Pustovalov, Zhur. Eksp. i Theoret. Fiz. 43, 2170 (1962).

[e] K. W. Ford and J. G. Wills, Nucl. Phys. 35, 295 (1962); Los Alamos Scientific Laboratory Report LASL-2387 (unpublished).

In the intermediate region, the energies of the K x rays were measured precisely to obtain information about the distribution of charge in the nucleus. Special precautions were taken to ensure that the accuracy of the measurements was limited by statistical factors and not by instrumental effects. In our experimental determinations of the x-ray energies (Table VII), the errors are only about a third of those in the values inferred from the electron-scattering data. The distribution used by Ford and Wills seems to yield energies that are consistently lower than the experimental results; and these differences are greater than the sum of the errors assigned to the experimental and calculated results.

The continuing program will be pursued at the Carnegie Institute of Technology in collaboration with R. B. Sutton and R. A. Carrigan. The detector of the x rays will be a Li-drifted Ge crystal. We have developed a detecting system with a crystal having a volume of about 12 cm^3. It is planned at this time to study the K x rays of the heavy muonic atoms with a resolution better than 15 keV. Many of the lines of the hyperfine structure of U^{238} and Th^{232} will be resolved by work with the new instrument. This will lead to more precise understanding of the shape of the nuclear charge and the actual radial distribution.

4. RADIATION-DAMAGE EFFECTS IN LITHIUM-DRIFTED SILICON DETECTORS BOMBARDED BY HEAVY PARTICLES

H. M. Mann* and J. L. Yntema

The charged-particle resolution width of Li-drifted silicon detectors was observed[1] to deteriorate when the detectors were exposed

*Electronics Division.

[1] H. M. Mann and J. L. Yntema, Trans. IEEE NS-11(3), 201 (1964).

to more than 10^8 particles. In particular, multiple peaking effects appeared in the spectra. The detectors usually could be restored even after exposure to 10^{12} particles.

5. PATTERN RECOGNITION FOR NUCLEAR EVENTS

C. Harrison, Jr.,* D. H. Jacobsohn,* and G. R. Ringo

The mechanization of the procedure for identification of interesting events is a problem of increasing importance in nuclear and particle physics. It is particularly critical in the case of emulsions where it is desirable to scan large volumes of material with microscopes showing volumes of 10^{-8} cc or less in a view. A general-purpose computer has been programmed to simulate a four-layer random-connection network similar in its general character to the Perceptron of F. Rosenblatt. This program is designed to separate patterns presented in the form of 80-bit words into wanted and unwanted classes after a learning phase using 100 cases of each. The approach differs from the original Perceptron in that in the original the random connections were reinforced or weakened on the basis of the learning performance. In the Argonne version, many completely different sets of connections are tried and the most useful (in the learning phase) kept. Preliminary results showed significant but not yet useful discrimination in a realistic but difficult case approximately equivalent to distinguishing X's from Y's of random size, orientation, and opening angle.

A drastic improvement in the speed of this technique has been obtained by building a special processing unit, DAPHNIS, which counts the number of 1's in an 80-bit word which is the logical product of two other 80-bit words, in a time of about 12 μsec. Unfortunately,

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because of a large number of difficulties with the system with which DAPHNIS is used, it has not yet given a critical test of the general strategy. There is a reasonable expectation, however, that it will do so in the next few months.

6. MICROSCOPIC LOCATION OF O^{17}, O^{18}, AND N^{15}

G. R. Ringo and J. P. Schiffer

Biologists have expressed the desire for a technique by which the tracer isotopes O^{17}, O^{18}, and N^{15} could be located (possibly simultaneously) within a resolution diameter of 1 micron or better. It is proposed to do this by sweeping a proton beam about 1 μ in diameter over a thin specimen of interest and using a semiconductor counter to detect the alpha particles from (p,α) reactions on the three isotopes mentioned. The output of the counter would be fed to a pulse-height analyzer which would select alphas with the energy characteristic of a particular isotope and transmit pulses to a TV display synchronized with the sweep of the proton beam. Low-energy protons striking the elements in typical biological materials appear to produce no nuclear reactions that would lead to confusing particles.

A magnetic quadrupole lens, sweeping circuits, and other apparatus for this system have been built and tested without encountering any difficulties that seem very fundamental. But the engineering problems, such as the production of a proton beam 1 μ in diameter, are not negligible. The smallest beam produced so far is 4×7 μ; more work will be needed to reduce this to a size of great biological interest.

II. THEORETICAL PHYSICS

The theoretical group consists of permanent staff and long- and short-term visitors. The largest theoretical effort goes into studies of nuclear structure and reactions. There is a major program in group theoretic and other symmetry theoretic methods (particularly as applied to elementary-particle physics), and work in statistical mechanics.

Activities of the group include several regular seminars. The general theoretical physics seminar draws in theorists from other divisions at Argonne and from nearby universities. A nuclear physics seminar is shared with experimental physicists at Argonne and with physicists from the University of Chicago and Northwestern University. These formal programs are supplemented by a variety of informal contacts with the above-mentioned groups, with many research collaborations. Members of the Argonne theoretical group also offer occasional courses at neighboring universities.

The theoretical group continues to attract large numbers of well-qualified applicants for temporary positions. Only a small number of these can be accepted for year-long visits. An active summer program makes it possible to accommodate many more visitors on a short-term basis. These are supported by Argonne National Laboratory, by Associated Midwest Universities, and by various outside agencies.

The largest single theoretical research project is the automated shell-model program, using the CDC-3600 computer. This project is now producing many valuable results, some of which are reported below. The project has also made valuable fundamental contributions in the area of automated computation.

1. THEORETICAL NUCLEAR SPECTROSCOPY

The use of the nuclear shell model to predict pertinent experiments and to interpret experimental data is now well established. Therefore, for the past three years an intensive effort has been made to completely automate this type of calculation. The system of programs described in last year's report is being extensively rewritten. The new versions will have enlarged capability and will be much more efficient. The experience gained from the older system has led to fundamental alterations in the structure of the programs. An algorithmic form of programming, now available, greatly eases the task of extending the capabilities of the system and it is believed that this new approach to programming will allow the system to be extended to encompass, in a coordinated manner, many allied fields. The new system constitutes the initial parts of a structure which will be greatly expanded in the next few years.

With the aid of these programs it is obviously possible to correlate an immense amount of nuclear data. The following are some of the problems that have been investigated during the past year.

a. 1p-Shell Nuclei

S. Cohen and D. Kurath

There is a wealth of experimental information about the 1p shell. At the same time the theoretical structure is sufficiently simple to permit a complete study for any number of neutrons and protons in the shell. Therefore the computer programs have been applied to extract an effective interaction for the 1p shell by fitting the energy data of the nuclear spectra. The resultant picture was checked by calculating magnetic dipole moments and probabilities for M1 gamma transitions and beta decay. Comparison of such quantities with experiment supports the validity of the extracted interaction.

The properties of the interaction are found to agree with the strong features of the phenomenological interaction deduced from nucleon-nucleon scattering. In particular, the results support the presence of a quadratic spin-orbit term in the interaction. A report has been prepared for publication.

b. Quadrupole Moment of Li^7

D. Kurath

The recently determined quadrupole moment of Li^7 cannot be adequately explained by a pure 1p-shell configuration. However, the required enhancement can be obtained by projecting wave functions by use of deformed single-particle orbitals. In this way the appropriate configuration mixing is determined by a single parameter, and an apparently complicated problem can be treated in a simple fashion. A report has been prepared for publication.

c. Potential Model for the Oxygen Isotopes

S. Cohen, R. D. Lawson, M. H. Macfarlane, S. P. Pandya, and M. Soga

It has already been shown[1] that the energy levels of O^{18}, O^{19}, and O^{20} can be fitted by use of the truncated $(d_{5/2}, s_{1/2})$ model when the eight T=1 two-body matrix elements are taken as parameters. This problem has also been examined by making explicit assumptions about the form of the residual two-body potential. The dominant characteristics of the spectra are determined by the spin-singlet force, and only this part of the interaction is well determined by the data. The strengths of the conventional triplet central, tensor, and spin-orbit potentials needed to fit the data change considerably with their range, with their assumed form (Gaussian or Yukawa), and with the inclusion of more single-particle levels. In these nuclei, the effects of a short-range repulsion, a velocity-dependent interaction, or a quadratic spin-orbit force can be simulated by a change in the range of the conventional forces.

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[1] S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga, Phys. Letters 9, 180 (1964).

d. $O^{18}(He^3,d)F^{19}$ Reaction[1]

J. R. Erskine, R. E. Holland, R. D. Lawson, M. H. Macfarlane, and J. P. Schiffer

In order to explain the gamma-ray transition rates and spectroscopic factors in O^{18}, it has been proposed that the low-lying states of this nucleus have components in which two protons are excited out of the $p_{1/2}$ level into the (d, s) shell. The strength of the $O^{18}(He^3,d)$ reaction to the 110-keV $\frac{1}{2}^-$ state in F^{19} provides, in principle, a measure of this core excitation. In view of the uncertainties in the DWBA analysis of stripping cross sections, reliable deduction of the small components in the wave function describing a nuclear state is difficult. Thus the best that can be said is that the experiment is consistent with about a 10% admixture of $(p_{1/2})^{-2}$ in the ground state of O^{18}.

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[1] J. R. Erskine, R. E. Holland, R. D. Lawson, M. H. Macfarlane, and J. P. Schiffer, Phys. Rev. Letters 14, 915 (1965).

e. M2 Lifetimes in the Scandium Isotopes

R. D. Lawson and M. H. Macfarlane

The experimental M2 lifetimes of the low-lying $d_{3/2}$-hole states in the scandium isotopes[1] were found to be approximately 200 times the single-particle estimate. The cancellation in the matrix element describing this transition can be explained if the eigenfunction describing the $\frac{3}{2}^+$ state contains a component in which the $d_{3/2}$ hole couples not only to the ground state of the even-even titanium core, but also to the first excited 2^+ state of the core. Eigenfunctions obtained by projecting states of good angular momentum from deformed oscillator orbitals take this effect into account and have been shown to give transition probabilities in excellent agreement with experiment.[2]

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[1] R. E. Holland, F. J. Lynch, and K.-E. Nystén, Phys. Rev. Letters 13, 241 (1964).

[2] R. D. Lawson and M. H. Macfarlane, Phys. Rev. Letters 14, 152 (1965).

f. Nickel Isotopes

S. Cohen, R. D. Lawson, M. H. Macfarlane, S. P. Pandya, and M. Soga

In these calculations on the nickel isotopes, the low-lying states are assumed to arise from putting neutrons in the $2p_{3/2}$, $1f_{5/2}$, and $2p_{1/2}$ orbitals. The existing data on the binding energies and excitation energies were fitted on the assumption that the effective interaction could be described by a four-parameter potential (central singlet, central triplet, tensor, and two-body spin-orbit—all with fixed ranges). This was found to produce very low excited 0^+ states. Since it is certainly true that one knows little about the residual two-body interaction when two particles are close together, the conventional potential was generalized by adding four more parameters describing the force when the two interacting nucleons are in relative s states. With these added parameters an excellent fit to the data was obtained. In addition, for the even-even nuclei the observed inhibition in the gamma-ray transition from the second 2^+ state to the ground state was explained. It was also found that an excellent description of the binding energies and excitation energies of the low-lying states in the even-even nuclei could be obtained by using only seniority-zero and seniority-two wave functions to describe the states.

g. Neutron-Proton Interaction in Nb^{92}

S. P. Pandya

The experimental identification of all the low-lying levels in Nb^{92} suggests that they all arise from coupling of a $1g_{9/2}$ proton to a $2d_{5/2}$ neutron. The spectrum provides information about the neutron-proton interaction in this configuration. A study of the theoretical spectra[1] shows that a central potential can reproduce the experimental results if a definite finite range is used in the interaction.

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[1] S. P. Pandya, Phys. Letters 10, 178 (1964).

h. Truncation of Shell-Model Problems

It is clear that even with the system of programs that has been written, only a very limited number of calculations are possible. As the number of nucleons increases, the problem quickly mushrooms in size and is not feasible to carry out even with the fastest computer available. One must, therefore, look for methods of truncating the already truncated shell-model problem. Much of our effort has proceeded along these lines.

(i) Quasi-Spin and Seniority (R. D. Lawson and M. H. Macfarlane). The work that has been done on the nickel isotopes and calculations[1] in the region of Zr^{90} have shown that the seniority classification scheme is extremely useful for identical nucleons. Since the seniority quantum number v and the quasi-spin quantum number S are related by

$$S = \frac{\frac{1}{2}(2j + 1) - v}{2} ,$$

one can also classify nuclear states by their quasi-spin and the z component of quasi-spin $S_z = [N - \frac{1}{2}(2j + 1)]/2$. The elementary creation and annihilation operators, whose matrix elements are related to the coefficients of fractional parentage (cfp) that come into a shell-model calculation, can easily be shown to be quasi-spin tensors of rank $\frac{1}{2}$.

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[1] S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga, Phys. Letters 10, 195 (1964).

Since the number dependence (N dependence) of the nuclear states arises only in S_z, the Wigner-Eckart theorem in quasi-spin space can be used to write down immediately the number dependence of the cfp's.[2] From this it follows that one can simply express the N dependence of any matrix element that enters into a shell-model calculation.

(ii) BCS Approximation (S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga). The Bardeen-Cooper-Schrieffer approximation, which was originally proposed in the theory of superconductivity, is based (in part) on the goodness of the seniority quantum number. It has already been shown[3] that for a Rosenfeld interaction this approximation gives results in good accord with exact calculations for certain low-lying nuclear states. The wave functions used in this approximation are not eigenstates of the number operator, and consequently this approach to nuclear spectroscopy can at best describe quantities that vary smoothly with N. The use of the quasi-particle formalism, discussed above, allows one to easily carry out calculations using BCS-type wave functions that are eigenfunctions of the number operator. This provides a powerful method of truncating a shell-model calculation when the valence nucleons are all of one type (either neutrons or protons).

(iii) Projection from Nilsson Orbitals (S. Cohen, D. Kurath, R. D. Lawson, and M. H. Macfarlane). For nuclei that have neither a closed neutron or proton shell, the eigenstates of the nuclear Hamiltonian have mixed seniority. In this case a possible method of truncating the set of basis states may be to use wave functions

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[2] R. D. Lawson and M. H. Macfarlane, Nucl. Phys. 66, 80 (1965).

[3] S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga, Phys. Letters 9, 180 (1964).

which are obtained by projecting from deformed oscillator orbitals (as was done in the M2 lifetime calculations reported above). It has already been shown[4] that the eigenfunctions obtained in this way agree quite closely with the shell-model calculations carried out in the p shell. This procedure also offers a method for calculating E2 enhancement as was done in the calculation of the Li^7 quadrupole moment reported above. Consequently, programs are now being written to automate this projection procedure.

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[4] D. Kurath and L. Pičman, Nucl. Phys. 10, 313 (1959).

2. COMPUTER PROGRAMMING

S. Cohen

The difficulties encountered in the construction of a program as complex as the nuclear shell-model system has led to the development of a new form of programming which is proving to be very versatile. The primary difficulties in carrying out large computer calculations are those associated with the allocation of storage space in fast memory and with the transmittal of information between various phases of the calculation.

a. Named Storage

An investigation of the means of avoiding these difficulties has led to the development of a programming technique that makes clear separations between the logic of the over-all calculation, the logic of specific parts of the calculation, and the actual means by which the computation is carried out. A scheme for dynamic allocation of memory[1] relieves the user of the difficulties encountered with this

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[1] S. Cohen, Argonne National Laboratory Report ANL-7021 (1964).

phase of programming. A virtue of this particular scheme is that the means by which actual calculations are directed is in a true sense an algorithmic specification of the logic of the calculation; it corresponds very closely to the form in which the user thinks of the operations he wishes to perform. He is therefore kept in close contact with his problem and need not concern himself with the details associated with its implementation. The problems of access to data produced in various parts of the calculation and the problems of having a program of such large size have been attacked by writing a supervisory program that directs the flow of the calculation and the exchange of information in a manner optimized for the configuration of the CDC-3600 computer.

The algorithmic routines for the shell-model calculations are for the most part complete. Additional routines for carrying out calculations in other closely connected studies are also being written, and the extension to less closely connected problems is being studied.

b. Simplified Communication with Computers

The structure of the programming system developed for the applications to nuclear shell-model studies lends itself to a new form of programming that greatly simplifies the directing of a computer by casual users. This development, referred to as SPEAKEASY, is a language that closely parallels the form of notation familiar to scientists. This simplified input specification of a problem means that with little effort a scientist can carry out calculations of the type that ordinarily have to be programmed in a language such as FORTRAN. It, however, avoids introducing the special notational conventions common in such languages.

A variation of this language, called HYDRA, is also particularly well adapted to "real time" communications to a computer. Such use of computers is being investigated. This use enables a person (whose memory is relatively slow but large) to interact sensibly with a machine that has a fast but small memory. Such interaction with a computer promises to facilitate research in various fields of physics.

3. STATISTICAL PROPERTIES OF NUCLEAR STATES, TRANSITIONS, AND CROSS SECTIONS

N. Rosenzweig

The investigation of the statistical properties of energy levels and transitions of highly excited nuclei has continued with two goals: (1) to determine whether the "local" theory (which describes the fluctuations within a band of energy over which the density of levels is practically constant) is quantitatively correct, and (2) to develop a "global" theory which will enable one to take account of structural features in the form of approximate constants of the motion.

a. Density of Nuclear Levels

A new level-density formula has been derived on the basis of a schematic version of a single-particle level scheme proposed by W. J. Swiatecki.

b. Finite-Sample Effects in the Spacing Distributions of Nuclear Levels

(with J. E. Monahan)

The consequences of the invariant Gaussian ensemble of real symmetric matrices were studied further in order to detect statistically significant deviations between theoretical and empirical spacing distributions. No real discrepancy between experiment and theory has turned up to date. However, it may be possible to devise sharper tests than have been used so far.

c. Information Theory and Hamiltonian Matrix Ensembles

The general principles of information theory have been used to define a variety of matrix ensembles which express our partial knowledge about the structure of a complicated physical system such as a nucleus or a complex atom. This approach was then applied (in collaboration with B. G. Wybourne*) to the "average" description of the complex atomic spectra encountered in the lanthanide region of the periodic table. Matrices of the electrostatic and spin-orbit interactions were examined in order to determine whether a meaningful statistical description of these spectra is possible. A particularly favorable case, in which it may be possible to see the effects of selection rules, has been singled out for further intensive study. Finally, Dyson's Brownian-motion model of a random matrix, which is the logical analytical tool in these problems, has been further developed.[1] The aim is to apply the random-matrix theory to systems with approximate constants of the motion.

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*Chemistry Division.

[1] N. Rosenzweig, Nuovo Cimento (in press).

4. DENSITY OF LEVELS WITH HIGH ANGULAR MOMENTUM IN EXCITED NUCLEI

D. W. Lang

The energy density of nuclear levels having a given spin has long been an important quantity for low spins. Recent experiments have shown that due to the existence of an actual upper limit to the values available for the spin at a given excitation, more energy is emitted in the form of gamma rays if much angular momentum is present. The form of the level densities close to the upper limit of angular momentum has been studied. It has been shown that the separation of thermal excitation and rotation as independent degrees of freedom (each associated with an excitation energy of the nucleus) is almost complete, and that this leads to an appropriate upper limit on the available spins.

5. THE INFLUENCE OF EXPERIMENTAL LIMITATIONS ON THE ACCURACY OF THE THEORY OF FLUCTUATIONS IN NUCLEAR CROSS SECTIONS

D. W. Lang

The Ericson theory for the analysis of nuclear cross sections implicitly assumes that the cross section is measured with unlimited accuracy over a range of energies of very great extent. Any actual experiment has a limited energy range. Each individual measured value of the cross section is an average over a small energy range, and even as a measure of this average it is limited in accuracy. Analysis is needed to check how badly the simple assumptions can be violated without the need of special correction, and to calculate the form of necessary corrections.

The resolution has been the subject of theoretical investigation and the conclusions have been checked with a computer. The main conclusion is that the average width of levels in the cross-section curve can be measured and corrected for imperfect resolution if the second moment of the resolution function of the experimental apparatus is known.

6. MONTE CARLO TESTS OF TECHNIQUES FOR THE DETERMINATION OF PARAMETERS FROM FLUCTUATIONS OF MEASURED NUCLEAR CROSS SECTIONS

D. W. Lang and P. P. Singh

The first program of a pair written for use on the CDC-3600 computer produces a sequence of numbers that could correspond to a set of nuclear cross sections over some range of energy. A Rosenfeld-Humblet form of the cross section is used. There are eight options about the forms of the direct part and of the distributions from which the parameters of the resonances are to be selected. Up to twelve numbers are also supplied to specify the mean values of quantities that appear in the cross section.

The results from this program are input for another program that was originally designed to handle experimental data. The object here is to check which input parameters can be recovered by analysis. Results to date[1] indicate that with the sort of samples obtained in normal nuclear experiments the average width can be recovered to within a factor of two, provided that the resolution is adequate.

The continuing effort will seek to find the effect of some boundary conditions imposed by the current matrix theories of nuclear collisions, and will try to find what features of "noise theory," from existing work on the output of telephone networks, can be usefully applied to discussion of nuclear cross sections.

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[1] D. W. Lang and P. P. Singh, Bull. Am. Phys. Soc. 10, 463 (1965).

7. ANALYTIC CRITERIA FOR SELECTING AN OPTIMUM SET OF MEASUREMENTS

J. E. Monahan and A. Langsdorf, Jr.

The criteria described in last year's report have been refined to a form such that it is possible to use a computer to program (and control) suitable experiments. A paper on this subject has been accepted for publication in the Annals of Physics.

8. THE EFFECT OF LONG-RANGE PERTURBATIONS IN SCATTERING

J. E. Monahan and A. J. Elwyn

The neutron-nucleus interaction can be written in terms of the electric field $\vec{E}$ of the nucleus, the magnetic moment μ of the neutron, the electric polarizability α_n of the neutron, and the potential V_N that describes the short-range nuclear forces in the form

$$V_N + |\mu| \frac{e\hbar}{2m^2c^2} \vec{\sigma} \cdot \vec{E} \times \vec{p} - \tfrac{1}{2} \alpha_n \vec{E}^2 .$$

Calculations[1,2] of the scattering from this potential show that the cross section and polarization of neutrons scattered through large angles ($\theta \geqslant 15^\circ$) are determined primarily by V_N while at small angles ($\theta \leqslant 5^\circ$) they are determined primarily by the electromagnetic interactions. At the intermediate angles, interference effects between these forces can be important. From an analysis of neutron-scattering and polarization data over a range of angles that includes all three of these intervals, it might be possible (1) to determine the value of the polarizability α_n and (2) to investigate the properties of any model

[1] J. E. Monahan and A. J. Elwyn, Phys. Rev. 136, B1678 (1964).

[2] J. E. Monahan, Bull. Am. Phys. Soc. 9, 638 (1964).

potential V_N once the electromagnetic terms in the neutron-nucleus interaction are completely specified. To date we have confined our attention primarily to (1).

The value of α_n is expected to be of the same order of magnitude as the corresponding value for the proton polarizability, i.e., $\sim 10^{-42}$ cm^3. Measurements (Sec. I.B.4) of the polarization and differential cross section of 0.83-MeV neutrons scattered from uranium through angles in the interval $2^\circ \leqslant \theta \leqslant 149^\circ$ have been analyzed in terms of the neutron-nucleus interaction described above. The potential V_N used was a diffuse-surface, surface-absorption, optical-model potential. These results appear to indicate a value $\alpha_n \approx 8 \times 10^{-40}$ cm^3 that is considerably larger than the value of the polarizability for a proton. A recent similar measurement elsewhere,[3] however, indicates that at $E_n = 0.570$ keV the value is $\alpha_n \lesssim 2 \times 10^{-40}$ cm^3. If α_n should prove to be smaller than this upper limit, the present results at 0.83 MeV exhibit a small-angle behavior that cannot be accounted for by the long-range interactions considered above (Fig. 26).

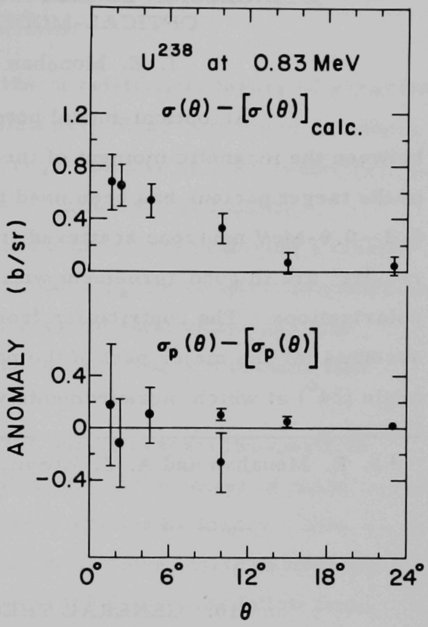

Fig. 26. The difference between the measured and calculated values of the differential and polarization cross sections.

[3] D. B. Fossan and M. Walt, Phys. Rev. Letters 12, 672 (1964).

9. INCLUSION OF MOTT-SCHWINGER SCATTERING IN OPTICAL-MODEL CALCULATIONS

J. E. Monahan and A. J. Elwyn

An optical-model potential that includes the interaction between the magnetic moment of the neutron and the Coulomb field of the target nucleus has been used to calculate the polarization of 0.3—0.9-MeV neutrons scattered from Zr, Nb, Mo, and Cd. The results[1] are in good agreement with the corresponding measured polarizations. The contribution from the electromagnetic interaction accounts for the major part of the polarization observed at the smallest angle (24°) at which measurements were made.

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[1] J. E. Monahan and A. J. Elwyn, Phys. Rev. 136, B1678 (1964).

10. GENERAL THEORY OF SCATTERING

H. Ekstein

The notes for lectures given at the University of Marseille have been organized into skeletal chapters of a projected book. The material written to date comprises 15 chapters in about 120 pages. The book emphasizes modern time-dependent Hilbert-space methods rather than the usual method of non-square-integrable solutions of partial differential equations.

11. RELATIVISTIC THEORY OF MULTIPARTICLE SCATTERING[1,2]

F. Coester

It is a common belief that a relativistic theory of particles in interaction requires fields (i. e., infinitely many degrees of freedom). The bases for this belief are locality requirements as well as the requirement of relativistic invariance. However, the locality requirement may be weakened to the point of merely requiring a cluster decomposition for the S matrix without affecting the relativistic invariance of the theory. It is then possible to formulate relativistic-particle quantum mechanics for a finite number of particles in a manner that readily admits soluble models.

The scattering theory for one or several two-particle channels can be formulated in the rest frame of the center of mass along the same lines as the nonrelativistic scattering theory. The existence and completeness of the scattering states, their asymptotic properties, and the Lorentz invariance of the S operator follow from known mathematical theorems. Since a many-particle system may break up into two or more noninteracting clusters, the dynamical description of the entire system must also contain the correct Lorentz-invariant description of each of the clusters. Macroscopically distinct scattering events must be causally related. These requirements can be satisfied.

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[1] F. Coester, Helv. Phys. Acta <u>38</u>, 7 (1965).

[2] F. Coester, Bull. Am. Phys. Soc. <u>10</u>, 125 (1965) (invited paper).

12. CONSISTENCY OF RELATIVISTIC PARTICLE THEORIES

H. Ekstein

The basic concept in all existing particle theories is the position of the particle at a sharply defined time. Yet, there are reasons of a theoretical nature to doubt the soundness of this concept. Like many other "obvious" notions, this one may have to be dropped.

The present paper[1] endeavors to give a precise definition of the particle concept without the use of the position, in the hope of eliminating certain inconsistencies between the postulate of finite signal velocity and the concept of directly-interacting relativistic particles, without mediating field. The conclusion is pessimistic — even without the position concept, direct-interacting relativistic particle theories are physically inconsistent, in classical as well as quantum mechanics.

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[1] H. Ekstein, Communications for Math. Phys. 1, 6 (1965).

13. INTERNAL SYMMETRY AND LORENTZ INVARIANCE[1]

F. Coester, M. Hamermesh, and W. D. McGlinn*

The notion of a rigorous internal symmetry implies an over-all symmetry group G that contains the inhomogeneous Lorentz group as a proper subgroup. Such a rigorous symmetry does not automatically require degenerate mass multiplets. But over-all symmetry groups that are compatible with mass splittings are severely restricted as follows. Assume that the generators of G are the Lorentz

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*High Energy Physics Division.

[1] F. Coester, M. Hamermesh, and W. D. McGlinn, Phys. Rev. 135, 451 (1964).

generators and the generators of either a semisimple or a compact Lie group. If the Cartan subalgebra of its semisimple part is Lorentz invariant, then all the generators of the internal symmetry are Lorentz invariant and therefore there can be no mass splitting. In particular, if the internal symmetry is SU(3) and T_z and Y are Lorentz invariant, then all the generators of SU(3) are Lorentz invariant.

14. RIGOROUS SYMMETRIES OF ELEMENTARY PARTICLES

H. Ekstein

The thesis of this paper[1] is that all rigorous symmetries can be inferred essentially from relativistic space-time symmetry. In particular, the existence of rigorous particle-antiparticle doublets (and no higher multiplets), the properties of charge and baryon number, and the invariance under combined charge inversion and space inversion follow from some simple physical principles added to relativistic invariance.

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[1] H. Ekstein, Ergeb. exakt. Naturwiss. 37, 150 (1965).

15. QUANTUM THEORY OF MEASUREMENT

M. N. Hack

Many physicists, finding it difficult to accept the Von Neumann interpretation of the reduction of the wave packet by an act of consciousness, have considered an alternative "wash-out of phases" type of theory that attempts to attribute the relevant feature of the measurement process to the experimental apparatus rather than to the observer himself.

In the course of an interesting recent article on the measuring process in quantum theory, the wash-out theory has been objected to on the following grounds: (i) the possibility of actual experimental confirmation of the interference capability that distinguishes the pure measurement superposition from the mixture, and (ii) the problem of intersubjective agreement between two or more observers under the assumption of the legitimacy of their use of the same mixture to describe the composite system prior to their observations.

These objections against the wash-out theory of phases have been discussed,[1] in particular in connection with the so-called weakened version of the wash-out theory, and the relation with the problem of time reversal was pointed out.

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[1] M. N. Hack, Bull. Am. Phys. Soc. 9, 148 (1964); Am. J. Phys. 32, 890 (1964).

16. STUDIES OF HYPERNUCLEI AND THE INTERACTIONS OF Λ PARTICLES

a. The $\Lambda\Lambda$ Hypernucleus $_{\Lambda\Lambda}Be^{10}$ and the Λ-Λ Interaction[1]

A. R. Bodmer and S. Ali*

The only $\Lambda\Lambda$ hypernucleus found so far is most probably $_{\Lambda\Lambda}Be^{10}$. For this the effects of distortion of the Be^8 core by the Λ particles are expected to be particularly important since Be^8 is not even bound. The energy gained by distortion of the core must be known if one is to reliably deduce the strength of the (singlet) Λ-Λ

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*Manchester University.

[1] A. R. Bodmer and S. Ali, Phys. Rev. 138, B644 (1965).

interaction from the experimental binding energy of ${}_{\Lambda\Lambda}Be^{10}$. In view of the success of an α-α-Λ model of ${}_{\Lambda}Be^{9}$,[2] an analysis of ${}_{\Lambda\Lambda}Be^{10}$ has been made with a 4-body α-α-Λ-Λ model. Λ-Λ Yukawa interactions with and without a hard core and also a meson-theoretical potential with a hard core were considered. For α-α potentials that give s-wave phase shifts in agreement with experiment, it is found that (almost independently of the details of the Λ-Λ interaction) core distortion accounts for more than a third of the experimental additional binding energy of 4.5 ± 0.5 MeV obtained after the Λ separation energy of ${}_{\Lambda}Be^{9}$ is allowed for. The second Λ causes the rms α-α separation to be approximately 10% smaller than the value for ${}_{\Lambda}Be^{9}$. The effects of core distortion weaken the resulting Λ-Λ interaction quite appreciably. Thus the well-depth parameters are considerably less than those obtained with a rigid core. The Σ-Λ-π coupling constant is close to the value obtained from the singlet Λ-N interaction for the same hard-core radius.

Extensive calculation for a variety of Λ-Λ interactions and α-Λ potentials have also been made for ${}_{\Lambda\Lambda}He^{6}$ with a 3-body α-Λ-Λ model by use of the method of Ref. 1. These results will be submitted for publication in the near future.

Preliminary results on an α-α-Λ model of the first excited state of ${}_{\Lambda}Be^{9}$ are in good agreement with the very recently obtained experimental value. In particular, this state is found to be unstable to decay into ${}_{\Lambda}He^{5}$ + He^{4} by about 0.3 MeV.

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[2] A. R. Bodmer and S. Ali, Nucl. Phys. 56, 657 (1964).

b. The Hypertriton with an S' State and the Λ-N Interaction

A. R. Bodmer

A variational calculation for the hypertriton ${}_{\Lambda}H^{3}$ has been made with the wave function $\Psi = \Psi_{s} + p\,\Psi_{s'}$. The component Ψ_{s}, the only one considered in previous works, has the neutron and proton in a triplet state with the space part symmetric to their interchange; $\Psi_{s'}$, which is the analogue of the S' state in the nuclear 3-body problem, has the nucleons in a singlet state—the space part being correspondingly antisymmetric. Only a spin dependence of the Λ-N interaction can give $p \neq 0$; but the spin dependence is thought to be large. The binding energy of $_\Lambda H^3$ then determines the volume integral $U_2 = \frac{3}{2} U_s + \frac{1}{2} U_t$. This is a function of Δ if $p \neq 0$. (U_s and U_t are the singlet and triplet volume integrals of the Λ-N interaction and $\Delta = U_s - U_t$.) Yukawa interactions and a very flexible 16-parameter trial function were used. For a range appropriate to the two-pion-exchange mechanism and with use also of the results obtained for $_\Lambda He^5$, it is then found that the singlet interaction is significantly smaller and that the spin dependence Δ is considerably reduced (by about a third) from the values obtained if only Ψ_s is considered. For shorter ranges the modifications due to $\Psi_{s'}$ become less.

c. The Mass-Seven Hypernuclei and the Mass-Six Nuclei[1]

A. R. Bodmer and J. W. Murphy*

The A = 7 hypernuclei ($_\Lambda Li^7$, $_\Lambda He^7$, $_\Lambda Be^7$) have been studied with a 2-body Λ/core-nucleus model. The strengths used for the Λ-N interactions are those obtained from the s-shell hypernuclei, $_\Lambda Be^9$ and $_\Lambda C^{13}$. Thus the Λ is in effect considered as a probe into the A = 6 cores since, because of uncertainties in the core sizes and rearrangement energies, no significant information about the Λ-N interaction is obtainable from the A = 7 hypernuclei with use of a Λ-core

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*Manchester University.

[1] A. R. Bodmer and J. W. Murphy, Nucl. Phys. 64, 593 (1965).

model. The Λ separation energies come out much too small if the effective s-shell sizes are taken to be about those of the isolated core nuclei, but are about right for much smaller sizes close to that of the α particle. The p-shell distribution is estimated to be only slightly compressed by the Λ; and the rearrangement energies of the cores are probably quite small ($\lesssim$ 0.5 MeV). Calculations with p nucleons moving in a square well show that reasonable wells again are obtained only if the s-shell size is close to that of an α particle. In view of the strong correlation expected between the Λ and the α particle, these results are interpreted as strong evidence that the structure of the A = 6 nuclei can be described as an α particle plus two nucleons. It is shown that the low value for the Λ separation energy of ${}_{\Lambda}He^{7}$ is most unlikely to be due to effects of rearrangement energy and must therefore be interpreted as due to an isomeric state.

Identifying the empirical binding-energy difference between He^{6} and the corresponding T=1 state of Li^{6} with the Coulomb-energy difference calculated with square-well p-nucleon wave functions gives an rms radius of 4.05 fm for the p-nucleon distribution, in close agreement with the value obtained with oscillator functions. Comparison of the calculated Coulomb-energy difference with the empirical binding-energy difference between He^{6} and Be^{6} indicates a tendency towards an α-dinucleon structure for the A=6, T=1 nuclei if effects due to a possible charge dependence of the nuclear forces are assumed to be small.

Preliminary results on a dynamical 3-body α-d-Λ model of ${}_{\Lambda}Li^{7}$ confirm the conclusion obtained with the Λ-core model and indicate that significant information may be obtainable about the range of the Λ-N interaction.

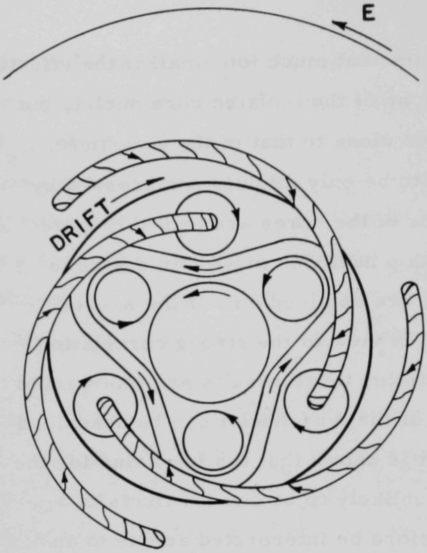

Fig. 27. Bundles of magnetic field lines being twisted by vortices driven by the jet stream in the fluid core of the earth. The fluid core occupies the region between the solid core (indicated by the innermost circle) and the electrically conducting mantle between the two outer concentric circles.

17. ORIGIN OF THE EARTH'S MAGNETISM

D. R. Inglis

The earth's magnetic field is generally believed to be caused by a dynamo action of the circulation within the fluid core, driven mainly by outward heat flow. Tentative explanations of the dynamo action have been presented both analytically and in terms of models. Laboratory experiments of Hide and others have suggested that the flow may have a pattern similar to that of the atmospheric jet stream. The snake-like path of the jet stream (Fig. 27) leaves isolated pockets of fluid having an almost cylindrical rotation. In a new and relatively simple hydromagnetic explanation of the dynamo action, the dominant support of the earth's field comes from the twisting of those bundles of lines of magnetic force that thread through the outer cylindrical regions, whose rotation does the twisting as indicated in the figure. These bundles form closed loops penetrating out into the mantle surrounding the fluid core, lagging to the east because of the westward drift of the flow pattern in the core.

The sense of the jet flow indicated in the figure is in keeping with the laboratory experiments as modified by considerations of the sense of the axial component of the pressure gradient. The drift of the pattern is maintained westward (as observed through field variations at the surface) presumably both because the "friction" between jet stream and mantle is greater than that between the slower cylindrical rotation and the mantle, and also because of the torque exerted by the large twisted bundle threading through the inner (solid) core.

Magnetic fields tend to collapse through a conducting fluid because of ohmic resistance to the currents supporting them; but the twisting action, tending to increase the component circulating around each bundle, maintains the local curl $\vec{H}$ and supports the global field surrounding the looped bundles.

III. EXPERIMENTAL ATOMIC PHYSICS

Four entirely different kinds of physics are included under the heading of Experimental Atomic Physics. These are studies of the Mössbauer effect, atomic-beam experiments, plasma physics, and the use of mass spectrometry to investigate various problems in chemical and surface physics. The mass-spectrometric studies have been greatly strengthened by the completion of three powerful experimental systems: a 2-MeV Van de Graaff generator (and associated equipment) intended primarily for surface studies, a mass spectrometer for the study of photoionization, and a pulsed-beam mass spectrometer.

A. MÖSSBAUER MEASUREMENTS

In the last few years, the Mössbauer effect has become a powerful tool for the study of many phenomena in solid-state, chemical, and low-energy nuclear physics. The experiments are aimed in two directions: (a) to yield accurate measurements of previously unobtainable nuclear properties (e.g., the quadrupole moments and magnetic moments of excited nuclear states) and (b) to make accurate determinations of the environment in which a nucleus is immersed (e.g., to determine the charge transfer from an iodine atom as it forms a chemical bond with chlorine). Recent Argonne experiments have been concerned with such diverse nuclear and chemical species as Fe^{57}, Sn^{119}, K^{40}, Kr^{83}, Cs^{133}, Xe^{129}, Xe^{131}, and I^{129}, and others are being considered.

a. Mössbauer Effect in Hexagonal Cobalt

G. J. Perlow, W. Marshall,* and C. E. Johnson*

Co^{57} plated epitaxially upon single-crystal hexagonal cobalt was used as a source in Mössbauer experiments. A magnetic field was applied either along the c axis or perpendicular to it. The small

*A. E. R. E., Harwell, England.

quadrupole shifting of the magnetically split hyperfine structure was observed to change in the appropriate way between the two cases, but the internal field at the emitter nucleus was found not to vary. Thus although there is an asymmetric charge distribution, the spin distribution is nearly spherical. The latter result is in concordance with results on neutron scattering.

b. Mössbauer Effect in Xenon Compounds

G. J. Perlow and M. R. Perlow

The effect in the 40-keV transition in Xe^{129} has been studied in various compounds. Of especial utility has been that class of xenon compounds which could be produced in the source by beta decay of iodine compounds. The quadrupole splittings and isomer shifts were measured and could be correlated.[1]

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[1] G. J. Perlow and M. R. Perlow, Rev. Mod. Phys. 36, 353 (1964); J. Chem. Phys. 41, 1157 (1964); and in Chemical Effects of Nuclear Transformations, Vol. 2 (International Atomic Energy Agency, Vienna, 1965), pp. 443—458.

c. Ratio of the Quadrupole Moment of the First Excited State of Xe^{129} to That of the Ground State of Xe^{131}

G. J. Perlow

The low-lying $\frac{3}{2}^{+}$ state in Xe^{129}, which had been assumed to be similar to the ground state of Xe^{131}, was found to have a quadrupole moment larger in magnitude by a factor of 3.5. Its sign was also measured and found to be negative (like that in Xe^{131}). The measurement was made by comparing the quadrupole coupling in XeF_4 for the two isotopes.[1]

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[1] G. J. Perlow, Phys. Rev. 135, B1102 (1964).

d. Quadrupole Moment of the First Excited State in I^{127} by the Mössbauer Effect

G. J. Perlow and S. L. Ruby

By making use of the large field gradients of the iodo-chloride ions, the quadrupole splitting in I^{127} has been observed. The ratio of excited-state to ground-state moments (including sign) is 0.896 ± 0.002, so that for the excited state $Q^* = -0.71$ barns. The new moment[1] fits closely on a linear plot of iodine quadrupole moments vs neutron number noted by others.

[1] G. J. Perlow and S. L. Ruby, Phys. Letters 13, 198 (1964).

e. Comparison of Iodine and Xenon Compounds

G. J. Perlow and M. R. Perlow

The isomer shifts have been measured in a variety of iodine compounds by use of stable I^{127}. It is possible to correlate these with quadrupole resonance measurements and to show the great similarity that exists between appropriate iodine and xenon compounds.[1]

[1] For the earlier results, see Proceedings of the IAEA Symposium on Chemical Effects Associated with Nuclear Reactions and Radioactive Transformations, Vienna, 1964.

f. Mössbauer Effect in Cs^{133}

G. J. Perlow, A. J. Boyle,* J. Marshall,† and S. L. Ruby

The Mössbauer effect has been observed for the 80-keV transition in Cs^{133}. The isomer shift has been observed with a variety

*On leave of absence from the University of Western Australia, Nedlands, Western Australia.

†Radiological Physics Division.

of sources and absorbers[1] and attempts are in progress to calibrate the shift.

[1] G. J. Perlow, A. J. F. Boyle, J. H. Marshall, and S. L. Ruby, Phys. Letters 17, 219 (1965).

g. Variation of the Fe^{57} Isomer Shift with Atomic Size in Laves Phases

R. S. Preston, C. W. Kimball,* and M. V. Nevitt†

Several experimenters have shown by a study of the isomer shift that the energy of the Mössbauer level relative to that of the ground state in Fe^{57} decreases with increasing hydrostatic pressure. This is a result of an increasing density of electrons at the nucleus and is attributed to the compression of outer (4s) electrons into a smaller volume as the volume available to each iron atom decreases.

Laves phases of composition XFe_2 provide another means of varying the atomic volume of iron. This volume, as determined from interatomic distances, varies with the size of the partner atom. We have measured the variation of the isomer shift (Fig. 28), and also of the

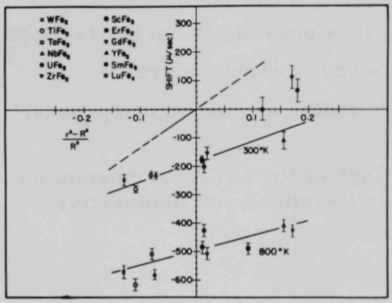

Fig. 28. Shift of the centroid, plotted against fractional change in volume for XFe_2 compounds. Shift and volume change are relative to Fe^{57} in α iron. The line passing through the origin is a fit to the high-pressure results (Pipkorn et al.) in α iron. The points taken at 800°K are the most significant for two reasons: First, the shift is insensitive to possible small differences in Debye temperature from one compound to another. Second, all samples are above their magnetic ordering temperatures, so that strong, sharp minima appear in the Mössbauer spectra. This makes it easier to determine the shift than at lower temperatures at which magnetic broadening makes the spectrum hard to measure.

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*Solid State Science Division and Northern Illinois University.

†Metallurgy Division.

magnetic hyperfine and electric quadrupolar fields, for Fe^{57} in a series of XFe_2 Laves phases.[1] From the observed variation of the isomer shift with composition, we find that the rate at which the density of electronic charge at the nucleus changes with decreasing volume of the iron atom has the same sign as for α iron under pressure, but is smaller. In no case is there a large total shift relative to α iron.

The fact that the changes in iron volume have a smaller effect in Laves phases than in α iron implies that the electronic configurations are different in the two cases. On the other hand, the smallness of the average value of the total shift in Laves phases relative to that in α iron implies that the electronic configurations are similar. We suggest that the electronic configurations are indeed similar, but that the relative orientations of the orbits of the unfilled d shells in adjacent iron atoms are different in the two cases so that in Laves phases a decrease in interatomic distance perturbs the electronic configuration less than it does for α iron.

[1] M. V. Nevitt, C. W. Kimball, and R. S. Preston, in Proceedings of the International Conference on Magnetism, Nottingham, England, 7—11 September 1964, p. 137.

h. Mössbauer Effect in V-Fe Alloys

R. S. Preston, C. W. Kimball,* D. J. Lam,† M. V. Nevitt,† and D. O. Van Ostenburg†

The most careful x-ray measurements on powdered V-Fe alloys in the range from 0 to 50% Fe indicate that when samples are quenched after being annealed at temperatures near 1000°C, they form

*Solid State Science Division and Northern Illinois University.

†Metallurgy Division, ANL.

body-centered cubic lattices with random distributions of V and Fe at the lattice sites. Our Mössbauer measurements, however, have already shown that over much of this range of concentrations there is actually a pseudo-CsCl ordering. That is, of the two interlocking simple cubic lattices that can be thought of as forming a single bcc lattice, one consists entirely of V and the other of a random mixture of V and Fe. This finding, which has since been confirmed by neutron-diffraction measurements on several V-Fe samples,[1] will necessitate revision of the standard phase diagram for the V-Fe system.

During experiments to find out why this ordering is not revealed by x-ray measurements, we observed that grinding the V-Fe samples to powder at room temperature produced magnetic ordering in alloys with 36—50% Fe. If the magnetic ordering is attributed to cold working, then it might be anticipated that the same powdered samples would also exhibit appreciable atomic disordering. However, Mössbauer measurements on powdered samples above their Curie temperatures do not reveal any significant departure from the pseudo-CsCl ordering.

Mössbauer measurements are more sensitive than x ray and neutron diffraction to small-scale atomic order, so that it may be difficult to disorder a crystal sufficiently by cold working to make the disorder apparent in Mössbauer measurements. The reason for the magnetic ordering produced by cold working will have to be discovered through x-ray and neutron-diffraction studies and from conventional magnetization measurements.

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[1] M. H. Mueller, Metallurgy Division, ANL (private communication).

i. Computation of Mössbauer Spectra[1]

S. L. Ruby and J. R. Gabriel*

In cases in which both magnetic and electrostatic interactions simultaneously perturb the energy levels of a nucleus being studied via Mössbauer techniques, previous methods of computing the resulting spectra have been either very inconvenient or quite impractical. Programs have now been constructed to enable the computer to give exact and prompt solutions to these problems; these programs are being made available to other laboratories.

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*Solid State Science Division.

[1] J. R. Gabriel and S. L. Ruby, Nucl. Instr. Methods (in press).

j. Mössbauer Effect in K^{40} Produced by an Accelerator[1]

S. L. Ruby and R. E. Holland

Until now, Mössbauer studies have been possible only when the excited nuclear state was produced by radioactive decay of a long-lived parent. For K^{40} no such parent exists; deuterons from the Van de Graaff were used to create the desired nuclear state via the $K^{39}(d,p)K^{40}$ reaction. No Mössbauer effect was observed in KBr or KOH but a small effect was seen in nominally metallic targets. These studies are being extended to other nuclides and it appears that it may originate a new method of studying radiation-damage effects.

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[1] S. L. Ruby and R. E. Holland, Phys. Rev. Letters (16 April 1965).

B. ATOMIC-BEAM RESEARCH

W. J. Childs, L. S. Goodman, and J. Dalman

During the past year, the Mark II atomic-beam magnetic-resonance apparatus has been used for the study of the hyperfine interactions in various atomic levels of Fe^{57}, Ge^{73}, Au^{197}, and V^{51}. In addition, studies of the Zeeman patterns of levels up to 10 000 cm^{-1} excitation in even-even isotopes of Fe, Ni, Mn, and Cr have yielded precise values of electronic g factors. These studies are of considerable value for the detailed understanding of atomic wave functions. They have also resulted in improved knowledge of certain nuclear properties.

Detailed studies of the magnetic hyperfine structure of four members of the ^5D ground-state multiplet of Fe^{57} has led to a better understanding of "core polarization." In this interaction, the electronic spin of the outer 3d electrons polarizes the inner s electrons of the atom and thus produces a strong magnetic field at the nucleus. The measurement provides an important test (and in this case, a confirmation) of the theory. Measurement of what may be the same effect in Ge^{73} is not in agreement with the theory, and indicates that further theoretical work should be done. The Ge^{73} experiment has, in addition, provided a better determination of the nuclear electric quadrupole moment of this isotope.

Precision measurements of the electronic g factors of 17 atomic energy levels in Fe, Ni, Mn, and Cr have provided information on the degree of spin-orbit mixing required. In the case of Ni, the extent of inter-configurational mixing was also examined critically.

Investigation of the magnetic and electric hyperfine interactions in the ^4F ground-state multiplet of V^{51} is proceeding rapidly. In addition to providing a measurement of the nuclear electric quadrupole moment, the study should be extremely useful in attempting

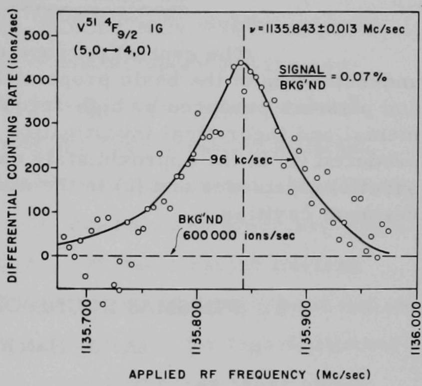

Fig. 29. A resonance in the $^4F_{9/2}$ metastable atomic state of V^{51}, as observed at a magnetic field of 1 G. In this case, the signal-to-background ratio was 0.07%, the counting rate was 600 000/sec, and a counting time of 80 min was required to collect the data shown. (If data had been taken at 12 points instead of 60, the same statistical uncertainty per point would have been achieved in 36 min.) Resonances for which the signal-to-background ratio is as small as 10^{-4} have been observed.

to understand in some detail the electronic wave functions of the low-lying levels. The study will be extended to higher multiplets.

Much of the work described above would not have been possible without the novel data-gathering system employed. When searching for a resonance at a given intensity of the homogeneous magnetic field, the radiofrequency used for inducing the transition is repeatedly swept (in small steps) through the frequency span of interest. Each time the frequency is stepped, the counts coming from the detector are switched to the next higher channel of a multichannel analyzer operating in the multiscaling mode. If a resonance occurs in a frequency interval corresponding to particular channels, the contents of these channels will grow more rapidly than the contents of those channels that are receiving only background counts. The result is thus effectively a digital lock-in system with arbitrarily long time constant and very great sensitivity, since fluctuations due to all causes except the resonance of interest are averaged out with ever-improving statistics while the resonance of interest grows steadily stronger. The effectiveness of this system is illustrated in Fig. 29.

C. HIGH-FREQUENCY PLASMAS

The central purpose of this research is to advance the understanding of the basic properties of low-pressure gaseous discharges and plasmas produced by high-frequency fields. The two lines of experimental and theoretical investigation being pursued are studies of plasmas produced (1) in the approximately uniform rf electric field between plane parallel electrodes and (2) in the nonuniform standing-wave fields in resonant cavities.

1. PLASMAS IN UNIFORM rf ELECTRIC FIELDS

A. J. Hatch and M. Hasan

An existing free-electron theory[1] of the admittance of bounded high-frequency gas discharges has been extended[2] to include the quasi-elastic binding of electrons by forces due to macroscopic charge inequality in sheaths. As shown in Fig. 30, a significant feature brought

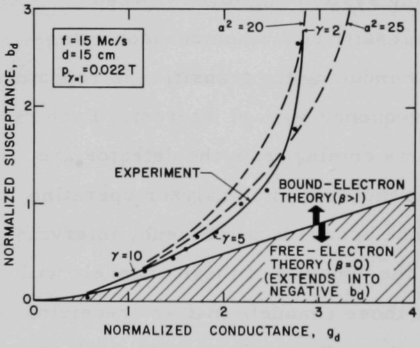

Fig. 30. Machine-calculated values of the components of the complex admittance $y_d = g_d + jb_d$ for a cosine axial distribution of electrons between infinite parallel-plate electrodes. The admittance has been normalized to the susceptance of the electrodes without discharge. The normalized parameters α^2, β, and γ represent the electron density, quasi-elastic force, and pressure (collision frequency), respectively. The data shown are for constant input rf power, approximately constant density, and pressures in the range 0.04—0.35 Torr. The dashed lines represent theoretical values of admittance for constant electron densities α^2 = 20 and 25 and β = 1.5.

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[1] E. Everhart and S. C. Brown, Phys. Rev. 76, 839 (1949).

[2] M. Hasan and A. J. Hatch, Bull. Am. Phys. Soc. 10, 236 (1965).

out by this study is that the positive-g_d half-plane is divided into two domains corresponding to the old free-electron theory and the new bound-electron theory. Experimental results such as those shown[3] were obtained at constant input rf power and approximately constant electron density. They are irreconcilable with the free-electron theory but exhibit promising correlation with the dashed lines which represent bound-electron theory values of admittance at two constant electron densities $\alpha^2 = \omega_p^2/\omega^2 = 20$ and 25. (These values of density have not yet been confirmed experimentally.) Other data (e. g., for high-frequency plasmoids for which values of $+b_d$ are even larger than those shown here) do not give such promising correlation, but it appears that this is due mainly to insufficiently accurate approximations used for the electron distribution (a cosine function here) and the binding force (a linear function here). This study is continuing.

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[3] A. J. Hatch, R. Freiberg, and S. V. Paranjape, Bull. Am. Phys. Soc. 9, 333 (1964).

2. MULTIPACTING SUPPRESSION

A. J. Hatch

A side experiment has recently been performed to test a new method of suppressing the multipacting mechanism of high-frequency breakdown which is notoriously troublesome in evacuated rf systems such as in cyclotrons, linacs, and other apparatus of high-energy physics. The method consists in inserting thin metallic or insulating baffles to subdivide the interelectrode space into gaps narrower than that for multipacting cutoff. The effectiveness of the method is shown by the experimental results in Fig. 31.

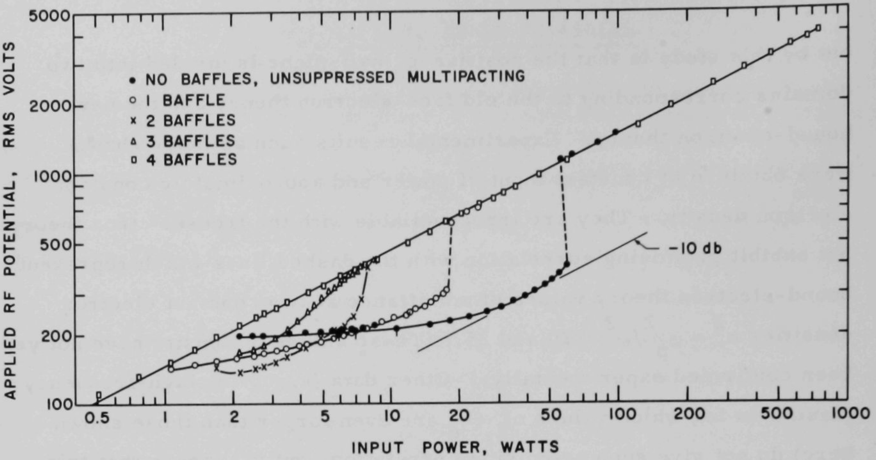

Fig. 31. Data showing the effectiveness of baffles in suppressing multipacting. The applied rf potential between the electrodes is measured as a function of the input rf power to the resonant circuit (shown in the insert). Solid circles (no baffles) show unsuppressed multipacting at a pressure $< 10^{-5}$ Torr. Open squares (4 baffles) show complete suppression; these points coincide with data at atmospheric pressure for no multipacting or discharge of any kind.

3. PLASMAS IN NONUNIFORM (CAVITY) ELECTROMAGNETIC FIELDS

A. J. Hatch

A recent paper[1] on the theory of electromagnetic levitation—in concert with several earlier publications—is addressed to the basic problem of the dynamic stability of conducting bodies in nonuniform alternating electromagnetic fields. Levitation is one facet of this problem; containment of dense plasmas is another. Now that it has been established that these two phenomena have a common theoretical foundation, the demonstrated phenomenon of electromagnetic levitation is additional evidence that the analogous stable steady-state containment of dense plasmas should also be demonstrable. Experimentally, the problem is

[1] A. J. Hatch, J. Appl. Phys. 36, 44 (1965).

that of locating the physical domain—e. g., pressure and input energy density—in which a dense plasma will coalesce into a sharply bounded quasi-metallic body in the vicinity of the nodal point of the quadrupole magnetic mode of a standing-wave electromagnetic field in a resonant cavity. That such plasma bodies can be formed is already indicated by the high-frequency plasmoids and related plasma structures studied in the uniform-field case. The UHF cavity and the auxiliary microwave equipment for this and related plasma experiments is being mounted and tested. Such work is expected to open a new avenue of research into the basic problem of the stable steady-state containment of dense hot plasmas suitable for controlled-fusion reactions and other applications. The significance of this approach is best appreciated by contrast with the inherent impossibility of such containment by the dc and quasi-dc pulsed magnetic fields employed in the containment systems that are currently popular in controlled-fusion research.

D. MASS-SPECTROMETRIC INVESTIGATIONS

The mass-spectrometric investigations involve seven instruments, each designed for a specified task. They include MA-15B, used primarily for the study of the molecular composition of high-temperature vapors and the kinetics of gas-phase reactions; MA-16B, designed for isotopic analysis by means of surface ionization of solid samples; MA-18, used in studies of photodissociation and collision-induced dissociation of molecular ions; MA-17, which incorporates an energy analyzer and is used for determining the kinetic energy distributions of fragment ions; MA-24, an unusually sensitive instrument which incorporates a vacuum ultraviolet monochromator and is used primarily for studies of photoionization; a portable mass spectrometer (MA-27) which can be used in conjunction with particle accelerators for the study of ionization in gases and sputtering of solids by high-energy particles; and a recently-completed pulsed molecular-beam mass spectrometer (MA-25) which offers a new approach in investigations of ions and neutral atoms desorbing from clean metal surfaces or scattering elastically from various clean solid surfaces.

In addition to the basic information that these studies provide about the fundamental atomic and molecular properties of matter (such information as molecular structure, the thermodynamics and kinetics of chemical reactions, and the nature of the interactions between thermal or high-energy atoms or ions and metal surfaces), the results of these investigations are applicable to problems involving nuclear reactor technology, radiation chemistry, direct energy conversion, rocket propulsion, radiation damage to space vehicles, and phenomena associated with the re-entry of such vehicles.

1. IONIZATION AND FRAGMENTATION OF GAS MOLECULES

a. Ionization Cross Sections by Electron-Impact Processes

J. Berkowitz and W. A. Chupka

Values of cross sections for ionization by electron impact are scarce, and remain one of the uncertainties in the determination of thermodynamic properties by mass spectrometric techniques. If values for these cross sections could be obtained at high electron kinetic energies, for which the Born approximation is valid, the dipole-moment matrix elements deduced from such measurements could provide a test for various semiempirical and theoretical estimates.

A program of determining relative ionization cross sections for a number of elements has been initiated. By comparing any one of these elements with one of the few materials for which absolute ionization cross sections are known, it is hoped that absolute values for all of the systems studied can be obtained.

One aspect of this work is to study the departure from additivity as the number of building blocks in a molecule increases. Earlier phases of this investigation have shown that it is possible to produce a vapor containing sulfur predominantly in the atomic form, or alternatively in the diatomic, in the hexatomic, or in the octatomic form. For each case, it is possible to determine the cross section of particular sulfur species relative to a standard. Hence, we hope to see the change of ionization cross section in the range S, S_2, S_6, S_8. A similar, though necessarily less extensive, program is under way with selenium.

b. Dissociation of Polyatomic Ions

W. A. Chupka and K. Refaey

A mass-spectrometric apparatus has been constructed for the purpose of detecting and investigating the photodissociation of gaseous ions. Some possible photodissociation of the propane ion was observed but a large background due to collision-induced dissociation made detailed measurements impossible. An improved source employing differential pumping to decrease this effect is being designed. Meanwhile, the phenomenon of collision-induced dissociation is itself being studied in an attempt to elucidate the mechanism of the process. The cross sections for a large number of different ions colliding with a number of different gases are being measured as a function of kinetic energy. The peak shapes are also measured since this provides information on angular deflection and energy loss in the collision.

c. Investigation of Photoionization

J. Berkowitz and W. A. Chupka

The construction of the new mass spectrometer MA-24 is virtually complete. The instrument has been put into operation and its performance tested. Although some minor adjustments and improvements are still required, its performance is already quite adequate for its intended uses. The vacuum ultraviolet photon monochromator associated with MA-24 has also been tested and put into operation as a photoionization source. The combination of monochromator and MA-24 has also been given a preliminary test which resulted in the measurement of resolved beams of ions about ten times as intense as those reported for similar apparatus at other laboratories. This increased sensitivity should make possible certain types of experiments that have not yet been performed, such as very precise determination of ionization potentials, dissociation energies, and the behavior of photoionization cross sections for high-temperature molecules. Successful development of such a technique would yield much more reliable and precise values than the present ones, which have been determined almost entirely by electron-impact and chemical thermodynamic techniques. Such data are essential to the understanding of the behavior of matter at high temperatures. In addition, the new apparatus will yield more detail and greater precision in continuing studies of the fundamental processes of ionization and fragmentation of gas molecules.

d. Study of Fragmentation Processes

The fragmentation of several molecules by electron impact under varying source conditions was studied with the energy-selecting mass spectrometer MA-17. The kinetic energy distributions of the fragments were measured and were analyzed to determine the energy of formation of each observed ion. Since the kinetic energies of the fragments were almost always quite small in the center-of-mass system, it was necessary to develop a method of analyzing the distributions to separate the energies of formation from thermal motions and possible instrumental effects.

(i) Fragmentation by Electron Impact[1] (H. E. Stanton and J. E. Monahan). The kinetic energy distributions were measured for over 30 ionic fragments from five molecules: CO, H_2O, NH_3, CH_4, and C_6H_6. The mathematical analysis devised for this study yielded the first three energy moments of the kinetic energy distribution of each ion. Since these moments were computed in the reference frame in which the precursor was at rest, they represent properties of the reaction that produced the ion. Although the energy distributions synthesized from only these three moments were necessarily somewhat crude and arbitrary, they indicated that few of the analyses were compatible with a Boltzmann distribution of ion energies; in most cases the ions were formed with practically no energy. At least qualitatively, these findings support the current postulate of quasi-equilibrium while the activated complex is separating into the fragments—provided that the parent molecule is large enough that the concepts are applicable. On the other hand, in the fragmentation of benzene to form the methyl ion and its companion, the parent molecule appears to be doubly ionized,

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[1] H. E. Stanton and J. E. Monahan, J. Chem. Phys. 41, 3694-3702 (1964).

the energy distribution shows two components, and the fragments are formed with considerable kinetic energy. As observed by others also, ions from simple molecules (e.g., CO) frequently had sizeable kinetic energies.

(ii) Fragmentation by Ion-Molecule Reactions (H. E. Stanton and S. Wexler*). Ion-molecule reactions take place when the source chamber of a mass spectrometer is operated at a relatively high pressure. Ions formed by electron impact collide with neutral molecules to form an ion-molecule complex whose subsequent fragmentation produces the ions that are detected and analyzed. Kinetic energy distributions were determined for three reactions: $C_2H_4^+ + C_2H_4$, $C_2H_2^+ + C_2H_4$, and $CH_3^+ + CH_4$. Since the mechanism of formation involved at least one ion-molecule collision in the source chamber, a further development of the moment analysis was required. In all cases, these reactions yielded ions with small kinetic energies—partly because of kinematics (light recoil fragment) and partly because the fragments are left in an excited state. Many of the complexes formed in ion-molecule reactions are similar to ions formed by electron impact or by reactions of ionic radicals created by normal fragmentation processes. Frequently, the fragments are in highly excited states similar to those found in plasmas or in the molecular products resulting from radioactive decay. The increasing interest in these fields will enhance the importance of studies of molecules, radicals, and complexes in ionized or highly excited states.

(iii) Improvements in the Mass Spectrometer MA-17 (H. E. Stanton). Completed improvements in MA-17 enable it to determine the intrinsic release of energy in fragmentation reactions in which the ions are formed with very low kinetic energies. The study

*Chemistry Division.

should now be extended to fluorocarbons, boranes, etc. Several improvements, including the installation of a multichannel analyzer, are planned to achieve higher stability, precision, and signal-to-noise ratio.

2. HIGH-TEMPERATURE STUDIES OF EQUILIBRIA AND CHEMICAL KINETICS

a. Optical Spectra of Laser-Ejected Jets

J. Berkowitz and W. A. Chupka

The optical spectra emitted by vapor jets ejected from solids by focused pulsed laser beams have been investigated further. The ejection of boron vapor into oxygen was found to produce a high intensity of the so-called "fluctuation bands" attributed to the molecule BO_2. Several new bands of this system have been observed.

b. Normal-Mode Vibrations of the S_6 Molecule

W. A. Chupka and J. Berkowitz

Last year's report described a normal-mode analysis of the D_{3d} symmetry of S_6. Then by borrowing force constants from S_8 it was possible to predict the characteristic frequencies of the normal modes. Two of the three infrared-active normal modes were observed, and their frequencies were rather close to the predicted values. More recently, with the assistance of Dr. Linn Belford, Department of Chemistry, University of Illinois, we have had access to a Raman-scattering apparatus which employs the output of a ruby laser as the incident light. With this device, three of the four Raman-active frequencies have been tentatively identified. The next step will be to refine the initial calculation by using successively better trial force constants until the best possible agreement with all of the observed frequencies is attained.

c. Vaporization Phenomena Involving Selenium

J. Berkowitz and W. A. Chupka

The vapor produced by selenium and some selected compounds of selenium at various temperatures and pressures has been analyzed mass spectrometrically. By applying thermodynamic principles to these data, the complex mass-spectral fragmentation pattern observed in saturated selenium vapor has been disentangled and the molecular composition of the vapor has been determined. The heats and free energies of formation of the various Se_n molecular species ($n = 1, 2, \cdots, 8$) have been determined. The energy per bond is seen to be greatest for Se_8 (as it was for S_8) although the most abundant vapor species in the saturated vapor are Se_5, Se_6, and Se_2 (in order of decreasing intensity). In the case of sulfur, the most abundant species were S_8, S_7, and S_6.

Both the metastable α-monoclinic form and the stable hexagonal form of selenium were studied in an attempt to observe the nonequilibrium behavior characteristic of sulfur vaporization. The observation that the mass spectra produced from α-monoclinic selenium and hexagonal selenium under free vaporization conditions were identical points to the establishment of equilibrium in both instances.

It seems fairly certain that the polyatomic molecular species composing sulfur vapors (S_3, S_4, $\cdots$, S_{10}) and selenium vapors (Se_3, Se_4, $\cdots$, Se_8) are puckered ring structures. A number of investigators have attempted to demonstrate the existence (or lack thereof) of mixed sulfur-selenium rings. We have mass spectrometrically investigated two types of samples: (a) the crystals formed when a saturated CS_2 solution of α selenium was also saturated with orthorhombic sulfur, and coprecipitation ensued, and (b) the crystals formed when a mixture composed of 30% selenium, 70% sulfur was heated to 300°C (above the melting point), maintained at that temperature for ca. 2 hours, and permitted to cool slowly. In case (a) the crystals contained predominantly sulfur and the mass spectrum was very similar to that of orthorhombic sulfur although some small penetration of the S_8 ring was indicated by the presence of S_7Se^+ in the spectrum. In case (b) a large variety of mixed molecular species were observed (e.g., S_7Se, S_6Se_2, S_5Se_3, S_4Se_4, as well as those corresponding to smaller rings).

3. ATOMIC IMPACT PHENOMENA ON METAL SURFACES (PULSED-BEAM STUDIES AT THERMAL ENERGIES)

M. Kaminsky

In the past year, construction of the pulsed-molecular-beam mass spectrometer MA-25 has been completed. The ultra-high vacuum and the new technique of combining modulated molecular beams with phase-sensitive mass-spectrometric detection allows measurements of the kinetics of ion desorption under very clean surface conditions. The very small intensities of the incident beam (10^9—10^{12} particles cm^{-2} sec^{-1}) obviate surface coverage by the beam atoms. For the first time it becomes possible to study quantitatively the effect of composition of the incident beam on the mean residence time τ_i of an ion on a metal surface.

The quantity τ_i depends on the surface temperature T through Frenkel's equation $\tau_i = \tau_i^0 \exp E_i/kT$, where E_i is the desorption energy of the ion. The values of τ_i^0 and E_i for the chlorides of the alkali metals were determined (Table VIII) over various temperature

TABLE VIII. Values of τ_i^0 and E_i for the desorption of alkali ions from clean and gas-covered polycrystalline tungsten surfaces.

	Atomically-clean W		Gas-covered W	
	$\tau_i^0 \times 10^{12}$ (sec)	E_i (eV)	$\tau_i^0 \times 10^{10}$ (sec)	E_i (eV)
Li^+			0.07 ± 0.02	2.38 ± 0.05
Na^+	0.20 ± 0.05	2.55 ± 0.03	0.12 ± 0.03	1.82 ± 0.05
K^+	0.62 ± 0.10	2.30 ± 0.03	0.41 ± 0.04	1.71 ± 0.02
Rb^+	1.55 ± 0.08	2.05 ± 0.02	1.10 ± 0.05	1.45 ± 0.03

TABLE IX. Values of τ_i^0 and E_i for the desorption of alkali ions from clean polycrystalline tungsten surfaces for incident atomic or molecular beam particles.

	Atomic sodium beam		Beam mixture: 45% Na, 24% NaCl, 31% Na_2Cl	
	$\tau_i^0 \times 10^{12}$ (sec)	E_i (eV)	$\tau_i^0 \times 10^{12}$ (sec)	E_i (eV)
Na^+	8.5 ± 0.5	2.69 ± 0.03	0.2 ± 0.05	2.55 ± 0.03

ranges within the region $1100^\circ K < T < 1900^\circ K$.[1,2] The atomic and molecular composition of the beam significantly affected τ_i^0 and E_i (Table IX). The observed changes in the E_i values are large enough (of the order of

[1] M. Kaminsky, Advances in Mass Spectrometry 3, Paper No. 19 (1965), in press.

[2] M. Kaminsky, Proceedings of the 25th Annual Conference on Physical Electronics, MIT, March 24, 1965, in press.

tenths of eV) to be taken into account in the decision of such important questions as whether the desorption energy can be described by the image force alone or needs to be corrected for certain systems by a covalent bonding contribution (also of the order of tenths of eV). Experiments to determine the desorption energy E_a of an adatom are now being conducted. The quantities E_i and E_a are related by the equation

$$E_a = E_i - e(I - \phi) - \Delta Q_i ,$$

where ΔQ_i is the heat of activation for the charge-transfer process, eI is the ionization energy of the desorbing particle, and $e\phi$ is the work function of the metal surface. With the aid of the now more accurately determined values of E_i, E_a, and $e\phi$, it will be possible to decide whether the adsorbate may exist on the surface in two different states (the atomic and ionic states, separated by the energy difference $\Delta Q_i \neq 0$) or not.

4. IONIC IMPACT PHENOMENA ON METALS (RUTHERFORD COLLISION REGION)

M. Kaminsky

a. Charged and Uncharged Particles from a Monocrystalline Target under High-Energy Ion Bombardment

With the newly-installed 2-MeV Van de Graaff and the portable mass spectrometer MA-27, the species of particles sputtered from monocrystals have been studied in the "Rutherford collision region" in which the incident ions are sufficiently energetic to interact with the lattice atom through the Coulombic repulsions of their nuclear charges. (All previous mass-spectroscopic studies of this problem had been restricted to the "hard-sphere collision region" in which the energy was too low to appreciably distort the electron clouds.)

In the past year, the (110) and (100) planes of Cu and Ag monocrystals were bombarded with p, d, and He^+ with energies E from 0.2 to 1 MeV.[1] Below 1 MeV the yield of singly-charged sputtered ions decreases with increasing ion energy (Fig. 32)—in part because the cross section for displacement of a lattice atom also decreases. Above 1 MeV, an increasing number of doubly-charged ions of the target material are observed, in accordance with the suggested[1] model of charge-changing collisions between energetic recoil atoms and quasistationary lattice atoms. The fact that the ratio of charged to uncharged sputtered particles (0.36 for 125-keV deuterons on Cu) in this energy region is three to four orders of magnitude higher than others have observed in the hard-sphere collision region supports the importance of charge-changing collisions and clearly demonstrates the inapplicability of the surface-ionization model used by others. Another surprising observation was the first mass-spectrometric detection of the radiation blistering of metals: the incident particles form gas bubbles in the target and the bubbles later explode and emit these particles in bursts. The total number of such bursts during the irradiation time was closely correlated with the total number of large etch pits in the bombarded surface (Fig. 33). This project will be extended to other types of incident ions, target materials (bcc metals), and ranges of incident ion energies.

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[1] M. Kaminsky, Advances in Mass Spectrometry 3, Paper No. 4 (1965), in press.

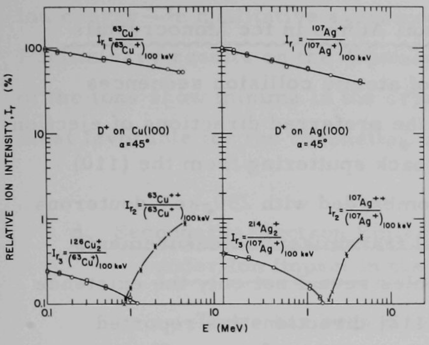

Fig. 32. Relative yields I_r of certain sputtered isotopic species of atomic and molecular ions of the target material plotted as functions of the incident-deuteron energy E.

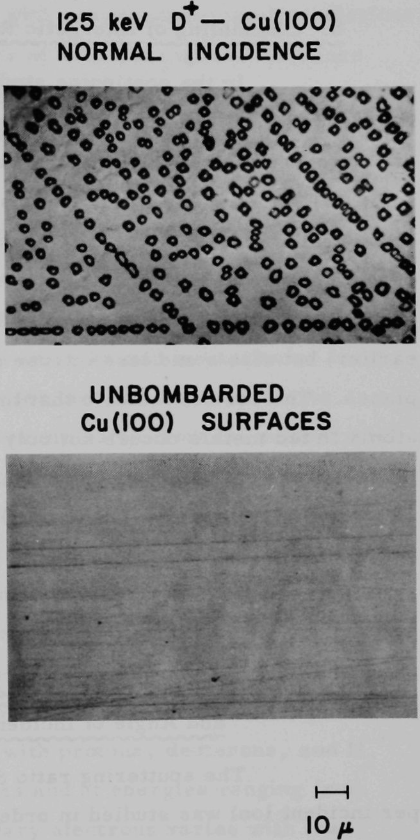

Fig. 33. Metallographs of a Cu (100) plane bombarded by 125-keV D^+ ions (Rutherford collision region) at normal incidence for nearly 800 μA-hr (upper micrograph) and for an unbombarded Cu (100) plane (lower micrograph).

b. Channeling of Energetic Recoil Atoms in fcc Monocrystals

In the continuing study of atomic collision sequences in face-centered cubic monocrystals, the preferred directions of ejection of particles have been determined for back sputtering from the (110) and (111) planes of Cu monocrystals bombarded with 250-keV deuterons at several angles of incidence. Optical transmission measurements of the deposits of back-sputtered particles reveal not only the existence of spots along the [110], [100], and [112] directions (as reported earlier) but also some less intense streaks related to the (111) and (100) planes. The results indicate that the channeling of energetic recoil atoms in fcc metals occurs not only between close-packed rows of lattice atoms but also between certain adjacent close-packed planes and that this process is dominant over the lens-focusing mechanism and the hard-sphere collision chain for the systems studied (Rutherford collision region).

c. Studies of the Sputtering Ratio in Dependence on the Energy and Angle of Incidence of the Incident Ion

The sputtering ratio S (the number of sputtered particles per incident ion) was studied in order to provide an adequate test of various theoretical models suggested for back sputtering in the Rutherford collision region. The previous observations of S for bombardment of Cu (100) and Ag (100) crystal planes with deuterons were supplemented by similar studies of the (110) and (111) planes of Cu over the energy range 0.2—0.4 MeV. The observation that at normal incidence S was greatest for the (111), less for the (100), and least for the (110) plane can be related to the varying effectiveness of the channeling mechanism along different crystallographic directions and planes. For all three of these planes in Cu, the sputtering ratio decreases with increasing ion energy—in qualitative agreement with certain theoretical predictions. Preliminary results on the dependence of S on the angle of incidence of the ions show minima in the crystallographic directions that are most favorable for the channeling of the incident ion.

d. Secondary-Electron Emission from Metal Monocrystal Planes under Ion Impact in the Rutherford Collision Region

There has been a complete lack of data on secondary emission from atomically clean metal surfaces and in particular from clean surfaces of metal monocrystals for the Rutherford collision region. To remedy this, the secondary emission from Cu monocrystal planes was studied for surfaces cleaned continuously by sputtering in a chamber evacuated to about 1.5×10^{-8} mm Hg. These experiments provide the first adequate test of two theoretical models[1,2] proposed for the Rutherford collision region; in particular it becomes possible to check if the yield values are independent of the crystalline orientation of the target surface, as predicted theoretically.[1]

In the present experiments,[3] the (100) and (111) planes of Cu monocrystals were bombarded with protons, deuterons, and H_2^+ and He^+ ions incident at various angles and at energies ranging from 0.5 to 1.0 MeV. The yield of secondary electrons varies with the crystallographic plane bombarded (contrary to theoretical expectations[1]) and for different ions [Fig. 34 (a and b)]. The yields are increased significantly when the surface becomes gas covered [Fig. 34(c)]. The

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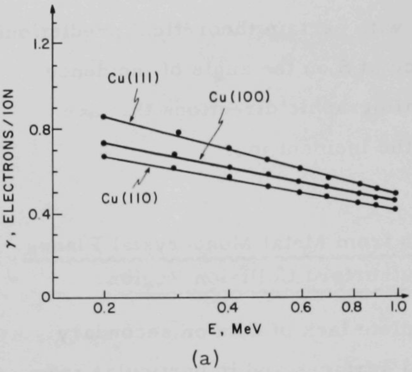
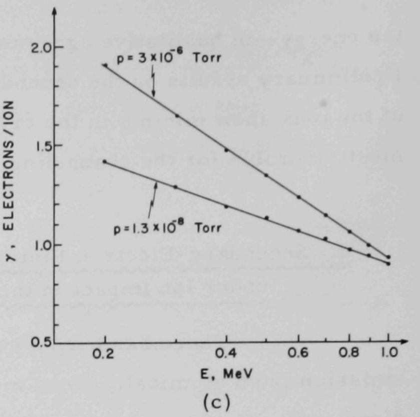
[1] E. J. Sternglass, Phys. Rev. 108, 1 (1957).

[2] S. N. Ghosh and S. P. Khare, Phys. Rev. 125, 1254 (1962); 129, 1638 (1963).

[3] M. Kaminsky and G. Goodwin, Proceedings of the 25th Annual Conference on Physical Electronics, MIT, March 24, 1965, in press.





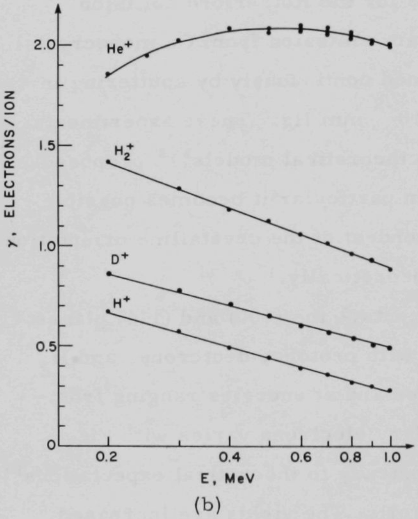


Fig. 34. The total secondary-electron yield from Cu monocrystals as a function of various parameters. (a) Dependence on the energy E of D^+ ions incident normal to the (100) and (111) surfaces. (b) Energy dependence for various ions at normal incidence on a (111) plane. (c) Effect of the background pressure p for $H_2{}^+$ ions incident normally on a (111) plane. For $p = 1.3 \times 10^{-8}$ Torr, the continuous sputtering of the surface layers guarantees a clean surface.

yield from He^+ ions passes through a broad maximum in this energy range, but that from the other three ions decreases with increasing ion energy. This observation indicates that the yield of secondary electrons is closely related to the cross section for ionizing a lattice atom. The measured energy distribution of the secondary electrons showed a pronounced maximum between 1.5 and 2.0 eV and two smaller peaks at higher energies (Fig. 35), in contrast to observations by others at lower

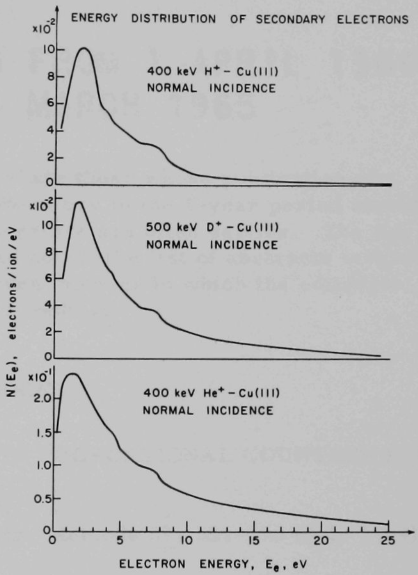


Fig. 35. Differential kinetic energy distributions for secondary electrons emitted from a clean Cu (111) plane under the impact of 400-keV H^+, 500-keV D^+, and 400-keV He^+ ions at normal incidence.

ion energies. The position of the main maximum can be related to the energy distribution of the excited electrons in the metal and to the surface potential barrier; the two smaller peaks correspond to two internal Auger processes.

5. INSTALLATION OF A 2-MEV VAN DE GRAAFF AND AN ASSOCIATED BEAM-HANDLING SYSTEM

J. Wallace and M. Kaminsky

The 2-MeV Van de Graaff generator has now been placed in its permanent position in the basement of the Physics Building and has been equipped with the appropriate shielding and services. It has its own shielded target room and a new beam-handling system. The particle energies have been extended down to about 200 keV, and a mass-analyzed beam up to more than 100 μA is available. Several experiments, especially those reported in Sec. III. D. 4, have already been performed with this machine.

Fig. 3. Differential energy distributions for secondary electrons emitted from a [illegible] (111) plane under the impact of [illegible] D^+, and [illegible] H^+ at normal incidence.

secondaries. The position of the main maximum can be related to the energy distribution of the excited electrons in the metal and to the surface potential barrier; the two smaller peaks correspond to two possible Auger processes.

48. INSTALLATION OF A 2-MEV VAN DE GRAAFF AND AN ASSOCIATED BEAM-HANDLING SYSTEM

J. [illegible] and M. Kaminsky

The 2-MeV Van de Graaff generator has now been placed in its permanent position in the basement of the [illegible] and has been equipped with the appropriate shield[illegible] and [illegible]. It [illegible] target room and a new beam-handling [illegible] particle energies have been extended down to [illegible] employed [illegible] than [illegible] available. Several experiments, especially those reported in Sec. [illegible], have already been performed with this machine.

IV. PUBLICATIONS FROM 1 APRIL 1964 THROUGH 31 MARCH 1965

The papers listed here are those whose publication was noted by the reporting unit of the Laboratory in the 1-year period stated above. The dates on the journals therefore are often earlier. The list of papers and books includes letters and notes; the list of abstracts includes all papers presented at meetings—even in cases in which the complete text was published in a volume of proceedings.

IV.1. PUBLISHED PAPERS AND BOOKS

1. He^3-Ne-CH_4 MIXTURES IN PROPORTIONAL COUNTERS FOR THERMAL NEUTRONS
   V. E. Krohn, Jr.
   Nucl. Instr. Methods <u>27</u>, 351-352 (July 1964)

2. He^3-Ne-CH_4 MIXTURES IN A PROPORTIONAL COUNTER FOR THERMAL NEUTRONS
   V. E. Krohn, Jr.
   Rev. Sci. Instr. <u>35</u>, 853-854 (July 1964)

3. TOTAL NEUTRON CROSS SECTION OF MANGANESE
   R. E. Coté, L. M. Bollinger, and G. E. Thomas
   Phys. Rev. <u>134</u>, B1047-B1051 (8 June 1964)

4. NEUTRON RESONANCES OF SELENIUM
   R. E. Coté, L. M. Bollinger, and G. E. Thomas
   Phys. Rev. <u>136</u>, B703-B710 (9 November 1964)

5. p-WAVE RESONANCES OF Th^{232}
   L. M. Bollinger and G. E. Thomas
   Phys. Letters <u>8</u>, 45-47 (1 January 1964)

6. TOTAL NEUTRON CROSS SECTION OF Cm^{244}
   R. E. Coté, R. F. Barnes (CHM), and H. Diamond (CHM)
   Phys. Rev. <u>134</u>, B1281-B1284 (22 June 1964)

7. EXCITED-STATE SPIN ASSIGNMENTS BASED ON (n, γγ) ANGULAR-CORRELATION MEASUREMENTS ON MEDIUM-WEIGHT NUCLEI
R. E. Coté, H. E. Jackson, Jr., L. L. Lee, Jr., and J. P. Schiffer
Phys. Rev. 135, B52-B56 (13 July 1964)

8. FLUCTUATIONS IN THE PARTIAL WIDTHS OF U^{239}
H. E. Jackson
Phys. Rev. 134, B931-B936 (8 June 1964)

9. NUCLEAR RESONANCE FLUORESCENCE IN Cu^{65}
G. B. Beard
Phys. Rev. 135, B577-B580 (10 August 1964)

10. ACTIVATION CROSS SECTION FOR Kr^{83m}
S. L. Ruby and R. Ellefson
Nucl. Sci. Engr. 21, 114-124 (January 1965)

11. POLARIZATION AND DIFFERENTIAL CROSS SECTION FOR NEUTRONS SCATTERED FROM Li^6 AND Li^7
R. O. Lane, A. J. Elwyn, and A. Langsdorf, Jr.
Phys. Rev. 136, B1710-B1719 (21 December 1964)

12. NEUTRON SCATTERING FROM NUCLEI NEAR A = 20 AT ENERGIES BELOW 2.2 MEV
A. J. Elwyn, J. E. Monahan, R. O. Lane, and A. Langsdorf, Jr.
Nucl. Phys. 59, 113-126 (October 1964)

13. INTERACTION BETWEEN THE NEUTRON MAGNETIC MOMENT AND THE NUCLEAR COULOMB FIELD IN NEUTRON POLARIZATION
J. E. Monahan and A. J. Elwyn
Phys. Rev. 136, B1678-B1681 (21 December 1964)

14. LIFETIMES OF $d_{3/2}$ HOLE STATES IN SCANDIUM ISOTOPES
R. E. Holland, F. J. Lynch, and K.-E. Nystén
Phys. Rev. Letters 13, 241-243 (17 August 1964)

15. $Ca^{40}(d,p)Ca^{41}$, A TEST OF THE VALIDITY OF THE DISTORTED-WAVE BORN APPROXIMATION
L. L. Lee, Jr., J. P. Schiffer, B. Zeidman, G. R. Satchler,* R. M. Drisko,* and R. H. Bassel*
Phys. Rev. 136, B971-B993 (23 November 1964)

*Oak Ridge National Laboratory.

16. THE ELASTIC SCATTERING OF 12.0-MEV He^3 PARTICLES BY NUCLEI
J. L. Yntema, B. Zeidman, and R. H. Bassel*
Phys. Letters 11, 302-304 (15 August 1964)

17. ELASTIC SCATTERING OF DEUTERONS BY Ca^{40}
R. H. Bassel,* R. M. Drisko,* G. R. Satchler,*
L. L. Lee, Jr., J. P. Schiffer, and B. Zeidman
Phys. Rev. 136, B960-B970 (23 November 1964)

18. STUDIES OF ELASTIC SCATTERING OF PROTONS, DEUTERONS, AND ALPHA PARTICLES FROM ISOTOPES OF Cu, Ni, AND Fe
L. L. Lee, Jr., and J. P. Schiffer
Phys. Rev. 134, B765-B772 (25 May 1964)

19. ISOBARIC-ANALOGUE STATES IN Cu^{65}
L. L. Lee, Jr., A. Marinov, and J. P. Schiffer
Phys. Letters 8, 352-354 (1 March 1964)

20. REDUCED WIDTHS AND STRENGTH FUNCTIONS
J. P. Schiffer
Rev. Mod. Phys. 36, 1065-1070 (October 1964)

21. DEPENDENCE OF THE ANGULAR DISTRIBUTION OF THE (d,p) REACTION ON THE TOTAL ANGULAR-MOMENTUM TRANSFER
L. L. Lee, Jr., and J. P. Schiffer
Phys. Rev. 136, B405-B409 (26 October 1964)

22. DEPENDNECE OF THE ANGULAR DISTRIBUTION IN THE (α,p) REACTION ON THE TOTAL ANGULAR-MOMENTUM TRANSFER
L. L. Lee, Jr., A. Marinov, C. Mayer-Böricke, J. P. Schiffer, R. H. Bassel,* R. M. Drisko,* and G. R. Satchler*
Phys. Rev. Letters 14, 261-263 (22 February 1965)

23. $B^{10}(d, Li^6)Li^6$ REACTION AT DEUTERON ENERGIES FROM 8 TO 13.5 MEV
D. S. Gemmell, J. R. Erskine, and J. P. Schiffer
Phys. Rev. 134, B110-B112 (13 April 1964)

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24. LEVEL STRUCTURE OF Bi^{208} AS OBSERVED AT HIGH RESOLUTION WITH THE $Bi^{209}(d,t)Bi^{208}$ REACTION
J. R. Erskine
Phys. Rev. 135, B110-B115 (13 July 1964)

25. NEW ISOTOPE K^{46} PRODUCED WITH THE $Ca^{48}(d,\alpha)K^{46}$ REACTION
A. Marinov and J. R. Erskine
Phys. Letters 14, 46-51 (1 January 1965)

26. THE ISOMERIC STATE OF Sc^{45}
J. L. Yntema and J. R. Erskine
Phys. Letters 12, 26-28 (1 September 1964)

27. RADIATIVE CAPTURE OF PROTONS BY B^{11} AND THE GIANT DIPOLE RESONANCE IN C^{12}
R. G. Allas, S. S. Hanna, L. Meyer-Schützmeister, and R. E. Segel
Nucl. Phys. 58, 122-144 (September 1964)

28. EVIDENCE FOR A SINGLE DOMINANT STATE FOR THE E1 GIANT RESONANCE
R. G. Allas, S. S. Hanna, L. Meyer-Schützmeister, R. E. Segel, P. P. Singh, and Z. Vager
Phys. Rev. Letters 13, 628-631 (23 November 1964)

29. ENERGY LEVELS OF Ar^{36} AND Ar^{38}
R. G. Allas, L. Meyer-Schützmeister, and D. von Ehrenstein
Nucl. Phys. 61, 289-296 (January 1965)

30. ELASTIC SCATTERING OF 21.0-MEV DEUTERONS BY He^4
H. W. Broek and J. L. Yntema
Phys. Rev. 135, B678-B679 (10 August 1964)

31. (d,He^3) REACTION ON Ca^{40} AND THE TITANIUM ISOTOPES
J. L. Yntema and G. R. Satchler*
Phys. Rev. 134, B976-B984 (8 June 1964)

32. SHELL-MODEL SELECTION RULES AND EXCITATION OF 4^+ STATES IN THE $Ti(\alpha,\alpha')$ REACTION
G. R. Satchler,* J. L. Yntema, and H. W. Broek
Phys. Letters 12, 55-56 (1 September 1964)

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33. THE GROUND-STATE CONFIGURATION OF Zr^{90}
J. L. Yntema
Phys. Letters 11, 140-141 (15 July 1964)

34. A SIMPLE REMOTELY-CONTROLLED TARGET CHANGER
J. T. Heinrich
Nucl. Instr. Methods 31, 337-338 (1964)

35. EXCITED STATES OF $_{56}Ba^{135}$ FROM THE DECAY OF $_{57}La^{135}$ (19.8 h)
H. A. Grench and S. B. Burson
Phys. Rev. 137, B483-B486 (8 February 1965)

36. LEVELS IN $_{75}Re^{188}$ FROM STUDIES OF THE DECAY OF $_{74}W^{188}$ (69.4 DAY), $_{75}Re^{188}$ (18 h), AND $_{75}Re^{188m}$ (18.5 MIN)
S. B. Burson, E. B. Shera, T. Gedayloo, R. G. Helmer, and D. Zei
Phys. Rev. 136, B1-B17 (12 October 1964)

37. TUNNEL DIODE TIME MARKER CIRCUIT FOR USE WITH SCINTILLATION COUNTERS
R. N. Larsen (EL) and E. B. Shera
Nucl. Instr. Methods 32, 168-170 (1965)

38. Sn^{116} LEVELS POPULATED BY THE DECAY OF 54-MIN In^{116m}
H. H. Bolotin
Phys. Rev. 136, B1557-B1565 (21 December 1964)

39. LEVEL STRUCTURE OF Sn^{116} FROM THE DECAY OF 1-h Sb^{116}; AND A DETAILED COMPARISON OF Sn^{116}, Sn^{118}, AND Sn^{120} WITH PAIRING-FORCE CALCULATIONS
H. H. Bolotin
Phys. Rev. 136, B1566-B1579 (21 December 1964)

40. ISOTOPIC EFFECTS IN THE X-RAY SPECTRUM OF MUONIC ATOMS OF Ca^{40} AND Ca^{44}
J. A. Bjorkland (EL), S. Raboy, C. C. Trail, R. D. Ehrlich,* and R. J. Powers*
Phys. Rev. 136, B341-B346 (26 October 1964)

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*University of Chicago.

41. EXPERIMENTAL OBSERVATION OF ELECTRIC-QUADRUPOLE HYPERFINE EFFECTS IN MUONIC X-RAY SPECTRA
R. D. Ehrlich,* R. J. Powers,* V. L. Telegdi,* J. A. Bjorkland (EL), S. Raboy, and C. C. Trail
Phys. Rev. Letters 13, 550-553 (2 November 1964)
Erratum: Phys. Rev. Letters 13, 650 (23 November 1964)

42. NEUTRON PRODUCTION BY 450-MEV PROTONS
J. W. Meadows (RP), G. R. Ringo, and A. B. Smith (RP)
Nucl. Instr. Methods 25, 349-352 (1964)

43. M2 LIFETIMES AND CORE EXCITATION IN THE SCANDIUM ISOTOPES
R. D. Lawson and M. H. Macfarlane
Phys. Rev. Letters 14, 152-154 (1 February 1965)

44. ON THE ACCURACY OF LINEARIZATION APPROXIMATIONS FOR SINGLE-CLOSED-SHELL NUCLEI
S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga†
Phys. Letters 9, 243-246 (15 April 1964)

45. EFFECTIVE SHELL-MODEL INTERACTION FOR THE ISOTOPES OF OXYGEN
S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga†
Phys. Letters 9, 180-183 (1 April 1964)

46. THE EFFECTIVE INTERACTION AND IDENTICAL-NUCLEON SENIORITY FOR NUCLEI NEAR Zr^{90}
S. Cohen, R. D. Lawson, M. H. Macfarlane, and M. Soga†
Phys. Letters 10, 195-198 (June 1964)

47. COUPLING SCHEMES AND EFFECTIVE INTERACTIONS IN THE NUCLEAR SHELL MODEL
S. P. Pandya and I. M. Green††
Nucl. Phys. 57, 658-674 (August 1964)

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*University of Chicago.

†Tokyo Institute of Technology.

††University of California, Los Angeles.

48. NEUTRON-PROTON INTERACTION IN Nb^{92}
S. P. Pandya
Phys. Letters 10, 178-179 (June 1964)

49. INTERMEDIATE COUPLING
D. Kurath
in Alpha-, Beta-, and Gamma-Ray Spectroscopy, edited by K. Siegbahn (North-Holland Publishing Co., Amsterdam, 1965), Vol. I, pp. 583-596

50. REVIEW OF "ASYMPTOTIC POWER OF TESTS OF LINEAR HYPOTHESES USING THE PROBIT AND LOGIT TRANSFORMATIONS" BY JAMES E. GRIZZLE
J. E. Monahan
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51. REVIEW OF "THEORY OF ASSOCIATED SYSTEMS FOR STUDY OF THE STABILITY IN THE LARGE" BY L. R. BORGES VIEIRA
J. E. Monahan
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52. ON FUTURE COMPUTING FACILITIES IN JAPAN
S. Cohen
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53. REVERSE ROTATION OF GAMMA-RAY ANGULAR PATTERN WITH CHANGING ALPHA-SCATTERING ANGLE
D. R. Inglis
Phys. Letters 10, 336-338 (15 June 1964)

54. ON THE THEORY OF STRIPPING REACTIONS
D. R. Inglis
Nucl. Phys. 57, 271-299 (August 1964)

55. FORM FACTORS FOR MAGNETIC-DIPOLE ELECTRON SCATTERING
D. Kurath
Phys. Rev. 134, B1025-B1027 (8 June 1964)

56. SYSTEMATIC APPROXIMATIONS FOR THE SINGLE-CHANNEL SCATTERING AMPLITUDE
F. Coester
Phys. Rev. 133, B1516-B1519 (23 March 1964)

57. INTERNAL SYMMETRY AND LORENTZ INVARIANCE
F. Coester, M. Hamermesh, and W. D. McGlinn
Phys. Rev. 135, B451-B452 (27 July 1964)

58. PSEUDOSCALAR CHARGE DENSITY OF SPIN-$\frac{1}{2}$ PARTICLES. I. EXISTENCE
K. Hiida
Phys. Rev. 134, B174-B181 (13 April 1964)

59. PSEUDOSCALAR CHARGE DENSITY OF SPIN-$\frac{1}{2}$ PARTICLES. II. OBSERVABILITY
K. Hiida
Phys. Rev. 134, B860-B863 (25 May 1964)

60. TWO-PION-EXCHANGE MODEL FOR $\pi + N \rightarrow N^* + \pi$ AND THE SECOND π-N RESONANCE
K. Itabashi
Nuoco Cimento 34, 93-100 (1 October 1964)

61. UNITARY SYMMETRY AND THE $K \rightarrow 2\pi$ DECAY
K. Itabashi
Phys. Rev. 136, B221-B222 (12 October 1964)

62. CONSEQUENCES ON CROSSING SYMMETRY IN SU_3
K. Itabashi and K. Tanaka
Phys. Rev. 135, B452-B454 (27 July 1964)

63. SU_3 INVARIANCE IN NUCLEON-ANTINUCLEON ANNIHILATION
K. Tanaka
Phys. Rev. 135, B1186-B1190 (7 September 1964)

64. VECTOR MESON DECAYS IN UNITARY SYMMETRY
K. Tanaka
Phys. Rev. 133, B1509-B1513 (23 March 1964)

65. PROBLEM OF COMBINING INTERACTION SYMMETRIES AND RELATIVISTIC INVARIANCE
W. D. McGlinn
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66. MESON-BARYON RESONANCES IN THE OCTET MODEL
A. W. Martin and K. C. Wali
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67. ASSIGNMENTS OF THE $d_{3/2}$ OCTET
A. W. Martin
Nuovo Cimento 32, 1645-1652 (16 June 1964)

68. APPROXIMATE BOOTSTRAP TECHNIQUE
A. W. Martin
Phys. Rev. 135, B967-B974 (24 August 1964)

69. ONE-NUCLEON EXCHANGE IN PION-NUCLEON SCATTERING
A. W. Martin and J. L. Uretsky
Phys. Rev. 135, B803-B809 (10 August 1964)

70. BARYON RESONANCES IN THE 10* SU_3 MULTIPLET
H. J. Lipkin
Phys. Letters 12, 154 (15 September 1964)

71. A POSSIBLE EXPLANATION FOR $K \rightarrow 2\pi$ DECAYS WITHOUT CP VIOLATION
H. J. Lipkin and A. Abashian*
Phys. Letters 14, 151-153 (15 January 1965)

72. FORBIDDEN TRANSITIONS IN POLE MODELS WITH UNITARY SYMMETRY
H. J. Lipkin
Phys. Rev. 137, B1561-B1565 (22 March 1965)

73. A UNITARY SYMMETRY SELECTION RULE AND ITS APPLICATION TO NEW RESONANCE
C. A. Levinson,† H. J. Lipkin, and S. Meshkov††
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74. HYPERNUCLEAR SPECTROSCOPY, UNITARY SYMMETRY, AND POSSIBLE ANALOG STATES
H. J. Lipkin
Phys. Rev. Letters 14, 18-20 (4 January 1965)

75. HIGHER SYMMETRIES AND STRANGE-PARTICLE PRODUCTION
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M. N. Hack
Am. J. Phys. 32, 890-892 (November 1964)

77. OBSERVABLES IN RELATIVISTIC QUANTUM MECHANICS
W. C. Davidon* and H. Ekstein
J. Math. Phys. 5, 1588-1594 (November 1964)

78. BARYON CONSERVATION IN SUPERDENSE STARS
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79. MEASUREMENT OF THE GRAVITATIONAL RED SHIFT WITH THE MÖSSBAUER EFFECT
T. E. Cranshaw† and J. P. Schiffer
Proc. Phys. Soc. (London) 84, 245-256 (August 1964)

80. MÖSSBAUER EFFECT EVIDENCE FOR THE EXISTENCE AND STRUCTURE OF $XeCl_4$
G. J. Perlow and M. R. Perlow
J. Chem. Phys. 41, 1157-1158 (15 August 1964)

81. RATIO OF THE QUADRUPOLE MOMENT OF THE FIRST EXCITED STATE OF Xe^{129} TO THAT OF THE GROUND STATE OF Xe^{131}
G. J. Perlow
Phys. Rev. 135, B1102-B1105 (7 September 1964)

82. QUADRUPOLE MOMENT OF THE FIRST EXCITED STATE IN I^{127} BY THE MÖSSBAUER EFFECT
G. J. Perlow and S. L. Ruby
Phys. Letters 13, 198-200 (December 1964)

83. MÖSSBAUER ANALYSIS OF IRON IN STONE METEORITES
E. L. Sprenkel-Segel (CHM) and S. S. Hanna
Geochim. Cosmochim. Acta 28, 1913-1931 (December 1964)

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†A. E. R. E., Harwell.

84. MAGNETIC MOMENT OF THE 26.8-KEV STATE OF I^{129} MEASURED WITH THE AID OF SUPERCONDUCTING MAGNETS
H. de Waard and J. Heberle
Phys. Rev. 136, B1615-B1617 (21 December 1964)

85. ELECTRONIC g FACTORS OF THE p^2 CONFIGURATION IN Ge I AND Sn I
W. J. Childs and L. S. Goodman
Phys. Rev. 134, A66-A69 (6 April 1964)

86. MAGNETIC HYPERFINE STRUCTURE OF THE $^3P_1$ AND $^3P_2$ METASTABLE STATES OF $Sn^{115,117,119}$
W. J. Childs and L. S. Goodman
Phys. Rev. 137, A35-A42 (4 January 1965)

87. BESTIMMUNG DER KERNMOMENTE DES Ho^{165} AUS DER HYPERFEINSTRUKTUR DES GRUNDZUSTANDES IM Ho I-SPEKTRUM
L. S. Goodman and K. Schlüpmann*
Z. Physik 178, 235-243 (1964)

88. POTENTIAL-WELL DESCRIPTION OF ELECTROMAGNETIC LEVITATION
A. J. Hatch
J. Appl. Phys. 36, 41-52 (January 1965)

89. CONSECUTIVE ION-MOLECULE REACTIONS IN ETHYLENE
S. Wexler and R. Marshall
J. Am. Chem. Soc. 86, 781-787 (5 March 1964)

90. ON THE KINETIC ENERGY DISTRIBUTION OF FRAGMENT IONS PRODUCED BY ELECTRON IMPACT IN A MASS SPECTROMETER
H. E. Stanton and J. E. Monahan
J. Chem. Phys. 41, 3694-3702 (15 December 1964)

91. MASS-SPECTROMETRIC STUDY OF THE REACTION OF WATER VAPOR WITH SOLID BARIUM OXIDE
F. E. Stafford† and J. Berkowitz
J. Chem. Phys. 40, 2963-2969 (15 May 1964)

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*University of Heidelberg

†Northwestern University.

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J. Berkowitz and W. A. Chupka
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IV.2. PATENT

1. METHOD AND APPARATUS FOR PRODUCING AND ANALYZING POLARIZED GAMMA RADIATION
M. Hamermesh, S. S. Hanna, and G. J. Perlow
U. S. Patent 3,130,315, 21 April 1964

IV. 3. PUBLISHED ABSTRACTS

1. A NEW ROTATING TARGET
   A. Langsdorf, Jr.
   in Accelerator Targets Designed for the Production of Neutrons, Proceedings of the Meeting Held at Liège (Belgium) on February 17—18, 1964, revised English edition (Euratom, Brussels, October 1964), EUR 1815. e, pp. 254-257

2. PHENOMENOLOGY BASED ON REGGE POLES
   B. M. Udgaonkar
   in Strong Interactions and High Energy Physics, edited by R. G. Moorhouse (Oliver and Boyd, Edinburgh, 1964), pp. 223-258

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   G. J. Perlow and M. R. Perlow
   IAEA Symposium on Chemical Effects Associated with Nuclear Reactions and Radioactive Transformations, Vienna, 7—11 December 1964. Abstracts of Papers, SM57/83

4. STERN-GERLACH EXPERIMENTS USING MASS SPECTROMETRIC DETECTION
   J. Berkowitz and L. S. Goodman
   Twelfth Annual Conference on Mass Spectrometry and Allied Topics, Montreal, 7—12 June 1964, p. 31

5. BOUND-ELECTRON THEORY OF ADMITTANCE OF HIGH-FREQUENCY GAS DISCHARGES
   M. Hasan and A. J. Hatch
   Bull. Am. Phys. Soc. 10, 236 (25—27 February 1965)

6. ADMITTANCE OF LOW-PRESSURE HIGH-FREQUENCY DISCHARGES
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7. ON PSEUDOSCALAR CHARGE DENSITY
   K. Hiida
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   C. A. Levinson,* H. J. Lipkin, and S. Meshkov†
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    H. M. Mann (EL) and J. L. Yntema
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12. NUCLEON CAPTURE REACTIONS NEAR A = 40
    J. L. Yntema and G. R. Satchler††
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*Weizmann Institute of Science.

†U. S. National Bureau of Standards.

††Oak Ridge National Laboratory.

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J. R. Erskine
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II. Proceedings, ANL-6878, pp. 277-278

15. SPIN MEASUREMENTS AND STRIPPING REACTIONS
J. P. Schiffer
II. Proceedings, ANL-6878, pp. 279-301

16. SINGLE-NUCLEON SPECTROSCOPIC FACTORS AND NUCLEAR MODELS
M. H. Macfarlane
II. Proceedings, ANL-6878, pp. 249-275

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L. M. Bollinger, R. E. Coté, and H. E. Jackson
p. 75 (abstract) and pp. 673-674 (text)

18. J DEPENDENCE OF (d,p) ANGULAR DISTRIBUTIONS
L. L. Lee, Jr., and J. P. Schiffer
p. 104 (abstract) and pp. 923-925 (text)

19. FLUCTUATIONS IN THE $K^{39}(p,\alpha)Ar^{36}$ REACTION
R. G. Allas, L. Meyer-Schützmeister, and D. von Ehrenstein
p. 78 (abstract) and pp. 695-696 (text)

20. STATISTICAL ANALYSIS OF THE $Al^{27}(p,\gamma)Si^{28}$ REACTION
P. P. Singh, R. E. Segel, L. Meyer-Schützmeister, S. S. Hanna, and R. G. Allas
p. 77 (abstract) and pp. 688-689 (text)

21. ANGULAR DISTRIBUTIONS IN THE GIANT-DIPOLE RESONANCE
R. G. Allas, S. S. Hanna, L. Meyer-Schützmeister, P. P. Singh, and R. E. Segel
p. 115 (abstract) and pp. 1020-1021 (text)

22. E1 STATES IN C^{12} AT 17.3 AND 19.2 MEV
S. S. Hanna, R. E. Segel, and R. G. Allas
p. 115 (abstract) and pp. 1022-1024 (text)

23. EXPERIMENTAL OBSERVATION OF ELECTRIC QUADRUPOLE HYPERFINE EFFECTS IN MUONIC X-RAY SPECTRA
R. D. Ehrlich,* R. J. Powers,* V. L. Telegdi,* J. A. Bjorkland (EL), S. Raboy, and C. C. Trail
p. 147 (abstract) and pp. 610-612 (text)

148th American Chemical Society meeting, Chicago, Illinois, 30 August—3 September 1964.

24. NORMAL COORDINATE ANALYSIS AND INFRARED SPECTRUM OF S_6
J. Berkowitz and W. A. Chupka
Abstracts of papers presented, p. 9-V

25. SPECTROSCOPIC STUDIES OF LASER-PRODUCED GRAPHITE JETS
W. A. Chupka and J. Berkowitz
Abstracts of papers presented, p. 60-V

American Physical Society meeting, Washington, D.C., 27—30 April 1964.

26. SPIN ASSIGNMENTS OF NEUTRON RESONANCES IN Hf^{177}
R. E. Coté and H. E. Jackson
Bull. Am. Phys. Soc. 9, 433 (April 1964)

*University of Chicago.

American Physical Society meeting, Washington, D.C., 27—30 April 1964 (cont'd.).

27. γ-γ ANGULAR CORRELATION IN Sm^{150}
R. K. Smither
Bull. Am. Phys. Soc. 9, 497 (April 1964)

28. ELECTROMAGNETIC POLARIZATION OF NEUTRONS AT LARGE SCATTERING ANGLES
J. E. Monahan and A. J. Elwyn
Bull. Am. Phys. Soc. 9, 443-444 (April 1964)

29. NEW NEUTRON RESONANCE IN B^{11}
F. P. Mooring and R. E. Segel
Bull. Am. Phys. Soc. 9, 434 (April 1964)

30. LIFETIME OF THE FIRST EXCITED STATE OF Ti^{45}
K.-E. Nystén, F. J. Lynch, and R. E. Holland
Bull. Am. Phys. Soc. 9, 457 (April 1964)

31. $F^{19}(He^3,d)Ne^{20}$ REACTION
R. H. Siemssen and L. L. Lee, Jr.
Bull. Am. Phys. Soc. 9, 430 (April 1964)

32. STUDIES OF ELASTIC SCATTERING OF PROTONS AND DEUTERONS FROM CALCIUM ISOTOPES
A. Marinov, L. L. Lee, Jr., and J. P. Schiffer
Bull. Am. Phys. Soc. 9, 457 (April 1964)

33. ISOBARIC-ANALOG STATES IN Cu^{65}
J. P. Schiffer, L. L. Lee, Jr., and A. Marinov
Bull. Am. Phys. Soc. 9, 472 (April 1964)

34. SPIN MEASUREMENTS FROM (d,p) ANGULAR DISTRIBUTIONS
L. L. Lee, Jr., and J. P. Schiffer
Bull. Am. Phys. Soc. 9, 457 (April 1964)

35. HIGH-RESOLUTION STUDY OF (d,p) REACTIONS ON TARGETS OF W^{182}, W^{184}, AND W^{186}
J. R. Erskine
Bull. Am. Phys. Soc. 9, 498 (April 1964)

American Physical Society meeting, Washington, D.C., 27—30 April 1964 (cont'd.).

36. ENERGIES OF THE K_α X RAYS IN MESONIC Ca^{44} AND Ca^{40}
R. J. Powers,* R. D. Ehrlich,* J. A. Bjorkland (EL), S. Raboy, and C. C. Trail
Bull. Am. Phys. Soc. 9, 394 (April 1964)

37. ENERGIES OF X RAYS FROM MU MESIC ATOMS WITH $12 \leqslant Z \leqslant 30$
S. Raboy, J. A. Bjorkland (EL), C. C. Trail, R. D. Ehrlich,* and R. J. Powers*
Bull. Am. Phys. Soc. 9, 393 (April 1964)

38. MU MESONIC X-RAY SPECTRA FROM HEAVY ELEMENTS
R. D. Ehrlich,* R. J. Powers,* V. L. Telegdi,* J. A. Bjorkland (EL), S. Raboy, and C. C. Trail
Bull. Am. Phys. Soc. 9, 393 (April 1964)

39. COUPLING SCHEMES AND EFFECTIVE INTERACTIONS IN THE NUCLEAR-SHELL MODEL
S. P. Pandya and I. M. Green†
Bull. Am. Phys. Soc. 9, 417 (April 1964)

40. MAGNETIC MOMENT OF THE 26.8-KEV STATE OF I^{129}
J. Heberle and H. de Waard
Bull. Am. Phys. Soc. 9, 452 (April 1964)

41. HYPERFINE STRUCTURE OF Ge^{73}
L. S. Goodman and W. J. Childs
Bull. Am. Phys. Soc. 9, 451 (April 1964)

American Physical Society meeting, Denver, 25—27 June 1964.

42. STATES IN A^{38} WITH EXCITATION ENERGIES BELOW 6.3 MEV
R. G. Allas, L. Meyer-Schützmeister, and D. von Ehrenstein
Bull. Am. Phys. Soc. 9, 553 (1964)

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*University of Chicago.

†University of California, Los Angeles.

American Physical Society meeting, Denver, 25—27 June 1964 (cont'd.).

43. INTERNAL SYMMETRY AND LORENTZ INVARIANCE
F. Coester, M. Hamermesh, and W. D. McGlinn
Bull. Am. Phys. Soc. 9, 537-538 (1964)

44. CHANNELING OF ENERGETIC RECOIL ATOMS IN fcc MONOCRYSTALS REVEALED BY SPUTTERING EXPERIMENTS IN THE RUTHERFORD COLLISION REGION
M. Kaminsky
Bull. Am. Phys. Soc. 9, 544 (1964)

American Physical Society meeting, Chicago, 23—24 October 1964.

45. BORON-LOADED NEUTRON DETECTOR WITH LOW γ-RAY SENSITIVITY
G. E. Thomas and H. E. Jackson
Bull. Am. Phys. Soc. 9, 652 (1964)

46. STUDY OF LOW-ENERGY NUCLEAR STATES IN Sr^{88} BY RESONANCE SCATTERING OF THERMAL-NEUTRON CAPTURE GAMMA RAYS
H. S. Hans, G. E. Thomas, and L. M. Bollinger
Bull. Am. Phys. Soc. 9, 651 (1964)

47. METASTABLE $d_{3/2}$-HOLE STATES IN Sc^{45} AND Sc^{47}
R. E. Holland, F. J. Lynch, and K.-E. Nystén
Bull. Am. Phys. Soc. 9, 650 (1964)

48. J DEPENDENCE IN $\ell_n = 2$ (d,p) REACTIONS ON Zr ISOTOPES
L. L. Lee, Jr., A. Marinov, Claus Mayer-Böricke, and J. P. Schiffer
Bull. Am. Phys. Soc. 9, 651 (1964)

49. NEW ISOTOPE K^{46}
A. Marinov and J. R. Erskine
Bull. Am. Phys. Soc. 9, 650 (1964)

50. $W^{182}(d,p)W^{183}$ REACTION AT 12 MEV
R. H. Siemssen and J. R. Erskine
Bull. Am. Phys. Soc. 9, 664 (1964)

American Physical Society meeting, Chicago, 23—24 October 1964 (cont'd.).

51. $F^{19}(p, \gamma)Ne^{20}$ GIANT RESONANCES
R. E. Segel, L. Meyer-Schützmeister, P. P. Singh, and Z. Vager
Bull. Am. Phys. Soc. 9, 665 (1964)

52. STUDIES OF $Mg^{24}(\alpha, \gamma)Si^{28}$
L. Meyer-Schützmeister, R. E. Segel, and Z. Vager
Bull. Am. Phys. Soc. 9, 666-667 (1964)

53. J DEPENDENCE OF ℓ=2 ANGULAR DISTRIBUTIONS FROM THE (d, p) REACTIONS ON Mg ISOTOPES
D. Dehnhard and J. L. Yntema
Bull. Am. Phys. Soc. 9, 666 (1964)

54. LIFETIMES OF $d_{3/2}$ HOLE STATES IN THE SCANDIUM ISOTOPES
R. D. Lawson, M. H. Macfarlane, M. Soga, and S. Cohen
Bull. Am. Phys. Soc. 9, 650 (1964)

55. SHELL-MODEL STUDIES OF THE ISOTOPES OF Ni
S. Cohen, R. D. Lawson, M. H. Macfarlane, S. P. Pandya, and M. Soga
Bull. Am. Phys. Soc. 9, 650 (1964)

56. EFFECTIVE NUCLEAR INTERACTION FOR THE 1p SHELL
D. Kurath
Bull. Am. Phys. Soc. 9, 628 (1964)

57. QUASISPIN AND THE n-DEPENDENCE OF SHELL-MODEL MATRIX ELEMENTS
M. H. Macfarlane, M. Soga, S. Cohen, and R. D. Lawson
Bull. Am. Phys. Soc. 9, 651 (1964)

58. QUADRUPOLE MOMENT OF THE FIRST EXCITED STATE IN I^{127}
S. L. Ruby and G. J. Perlow
Bull. Am. Phys. Soc. 9, 663 (1964)

American Physical Society meeting, Chicago, 23—24 October 1964 (cont'd.).

59. METHOD OF MEASURING THE ABSOLUTE VALUE OF THE ABSORPTION INTEGRAL OF A MÖSSBAUER ABSORBER
J. Heberle
Bull. Am. Phys. Soc. 9, 634 (1964)

60. SEARCH FOR STABLE, FRACTIONALLY CHARGED PARTICLES IN NATURE
C. M. Stevens (CHM), W. A. Chupka, and J. P. Schiffer
Bull. Am. Phys. Soc. 9, 642 (1964)

American Physical Society meeting, New York, 27—30 January 1965.

61. LOW-LYING EXCITED STATES OF Sc^{46} FROM $Sc^{45}(n,\gamma)Sc^{46}$
H. H. Bolotin
Bull. Am. Phys. Soc. 10, 12 (1965)

62. COMBINATION OF A BENT-CRYSTAL SPECTROMETER AND A Ge DIODE FOR HIGH-RESOLUTION GAMMA-RAY STUDIES
R. K. Smither and A. Namenson
Bull. Am. Phys. Soc. 10, 54 (1965)

63. INTERCALIBRATION OF (n,γ) AND γ SPECTRA FOLLOWING β DECAY THROUGH THE USE OF A BENT-CRYSTAL SPECTROMETER AND A Ge DIODE ASSEMBLY
A. Namenson and R. K. Smither
Bull. Am. Phys. Soc. 10, 54 (1965)

64. CHANNELLING OF 3.6-MEV PROTONS THROUGH A SINGLE CRYSTAL OF Si
J. P. Schiffer and R. E. Holland
Bull. Am. Phys. Soc. 10, 54 (1965)

65. PARTIAL M2 LIFETIME OF THE $d_{3/2}$ HOLE STATE OF Ca^{43}
R. E. Holland, F. J. Lynch, and H. M. Mann (EL)
Bull. Am. Phys. Soc. 10, 119 (1965)

American Physical Society meeting, New York, 27—30 January 1965 (cont'd.).

66. $Ca^{46}(d,p)Ca^{47}$ REACTION
A. Marinov, L. L. Lee, Jr., C. Mayer-Böricke, and J. P. Schiffer
Bull. Am. Phys. Soc. 10, 39 (1965)

67. YIELD CURVES OF $Ni^{58}(p,p')$
A. Elwyn, L. L. Lee, Jr., L. Meyer-Schützmeister, J. E. Monahan, R. E. Segel, P. P. Singh, and Z. Vager
Bull. Am. Phys. Soc. 10, 104 (1965)

68. LEVELS IN ODD-MASS YTTERBIUM NUCLEI POPULATED BY (d,t) AND (d,p) REACTIONS
D. G. Burke,* B. Elbek,* B. Herskind,* M. C. Olesen,* and B. Zeidman
Bull. Am. Phys. Soc. 10, 40 (1965)

69. INELASTIC DEUTERON SCATTERING FROM EVEN ISOTOPES OF SAMARIUM
B. Zeidman, D. G. Burke,* B. Elbek,* B. Herskind,* and M. C. Olesen*
Bull. Am. Phys. Soc. 10, 40 (1965)

70. J DEPENDENCE IN THE (He^3, α) REACTION: $Fe^{56}(He^3, \alpha)Fe^{55}$
C. Mayer-Böricke, R. H. Siemssen, and L. L. Lee, Jr.
Bull. Am. Phys. Soc. 10, 26 (1965)

71. DEPENDENCE OF THE ANGULAR DISTRIBUTION FROM THE (α, p) REACTION ON THE TOTAL ANGULAR-MOMENTUM TRANSFER: $Ni^{58,60}(\alpha,p)Cu^{61,63}$
L. L. Lee, Jr., A. Marinov, C. Mayer-Böricke, and J. P. Schiffer
Bull. Am. Phys. Soc. 10, 26 (1965)

73. ENERGY LEVEL STRUCTURE OF U^{237} AS OBSERVED WITH THE $U^{236}(d,p)U^{237}$ REACTION
J. R. Erskine, A. M. Friedman (CHM), and T. H. Braid
Bull. Am. Phys. Soc. 10, 40 (1965)

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*Institute for Theoretical Physics, Copenhagen.

American Physical Society meeting, New York, 27—30 January 1965 (cont'd.).

74. SEARCH FOR A 4.97-MEV DOUBLET IN Ne^{20}
L. Meyer-Schützmeister and R. E. Segel
Bull. Am. Phys. Soc. 10, 10 (1965)

75. PROPOSAL FOR A MORE INTENSE SOURCE OF COMPLETELY POLARIZED DEUTERONS
D. von Ehrenstein, D. C. Hess, and G. Clausnitzer*
Bull. Am. Phys. Soc. 10, 55 (1965)

76. DELAYED PROTON EMISSION FROM ISOTOPES OF NEON, SULPHUR, AND ARGON
T. H. Braid, A. M. Friedman (CHM), and R. W. Fink†
Bull. Am. Phys. Soc. 10, 120 (1965)

77. HYPERFINE STRUCTURE (hfs) EFFECTS IN THE SPECTRA OF MUONIC ATOMS WITH $I \neq 0$ NUCLEI
R. D. Ehrlich,†† R. J. Powers,†† V. L. Telegdi,†† J. A. Bjorkland (EL), S. Raboy, and C. C. Trail
Bull. Am. Phys. Soc. 10, 121 (1965)

78. SHELL-MODEL STUDY OF THE CALCIUM ISOTOPES
B. J. Raz,‡ S. P. Pandya (HEP), and M. Soga
Bull. Am. Phys. Soc. 10, 26 (1965)

79. HYPERTRITON WITH AN S' STATE AND THE Λ-N INTERACTION
A. R. Bodmer
Bull. Am. Phys. Soc. 10, 18 (1965)

80. MÖSSBAUER-ABSORPTION INTEGRAL OF WHITE TIN AT LIQUID-NITROGEN TEMPERATURE
P. S. Eastman and J. Heberle
Bull. Am. Phys. Soc. 10, 64 (1965)

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*University of Erlangen, Germany.

†Marquette University.

††University of Chicago.

‡State University of New York, Stony Brook.

American Physical Society meeting, New York, 27—30 January 1965 (cont'd.).

81. LINEWIDTH OF MÖSSBAUER ABSORPTION
J. Heberle
Bull. Am. Phys. Soc. 10, 64 (1965)

82. MÖSSBAUER EFFECT IN Cs^{133}
J. H. Marshall (RPY), G. J. Perlow, and S. L. Ruby
Bull. Am. Phys. Soc. 10, 64 (1965)

IV.4. ANL TOPICAL REPORTS

1. NUCLEAR SPECTROSCOPY WITH DIRECT REACTIONS. II. PROCEEDINGS
   edited by F. E. Throw
   Nuclear Spectroscopy with Direct Reactions. II. Proceedings, Argonne National Laboratory Report ANL-6878 (March 1964)

2. WHADDAYADOO WITH THE DIDJERIDOO? (A GENERALIZED ASI-2100 PROGRAM FOR HANDLING DATA FROM THE ND-160 PULSE-HEIGHT ANALYZER)
   D. S. Gemmell
   Argonne National Laboratory Topical Report ANL-6993 (December 1964)

3. NAMED STORAGE (A DYNAMIC STORAGE ALLOCATION SCHEME WITH MANIPULATIVE ROUTINES)
   S. Cohen
   Argonne National Laboratory Topical Report ANL-7021 (20 July 1964)

4. UNITARY SYMMETRY FOR PEDESTRIANS (OR, I-SPIN, U-SPIN, V-ALL SPIN FOR I-SPIN)
   H. J. Lipkin
   Argonne National Laboratory Topical Report ANL-6942 (September 1964)

V. STAFF MEMBERS OF THE PHYSICS DIVISION

The Physics Division staff for the year ending 1 April 1965 is listed below. Although the members are classified by programs, it must be understood that many of them work in two or more of the areas. In such cases, the classification indicates only the current primary interest.

In the period from 1 April 1964 through 31 March 1965, there were 24 temporary staff members (16 staff members from universities and other laboratories and 8 post-doctoral fellows), 6 graduate students (including 4 doing thesis research), and 14 undergraduates (6 in the Argonne Semester program of the Associated Colleges of the Midwest, 4 co-op technicians, and 4 on summer appointments).

RESEARCH AT THE REACTOR CP-5

Permanent Staff

Lowell M. Bollinger,* Ph. D., Cornell University, 1951

Merle T. Burgy, B. S., University of Chicago, 1939

Robert E. Coté, Ph. D., Columbia University, 1953

Harold E. Jackson, Jr., Ph. D., Cornell University, 1959

Victor E. Krohn, Ph. D., Case Institute of Technology, 1952

Allen P. Magruder, B. S., University of Chicago, 1959

J. P. Marion, M. S., DePaul University, 1959

Sol Raboy, Ph. D., Carnegie Institute of Technology, 1950

G. R. Ringo, Ph. D., University of Chicago, 1940

Robert K. Smither, Ph. D., Yale University, 1958

George E. Thomas, Jr., B. A., Illinois Wesleyan University, 1943

Carroll C. Trail, Ph. D., Texas A & M College, 1956

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*Director of Physics Division.

Resident Research Associates

Harnam S. Hans, Ph. D., Aligarh Muslim University, 1953

Arthur I. Namenson, Ph. D., Columbia University, 1963

FAST-NEUTRON REACTIONS

Permanent Staff

Alexander Elwyn, Ph. D., Washington University, 1956

Carl T. Hibdon, Ph. D., Ohio State University, 1944

Raymond O. Lane, Ph. D., Iowa State University, 1953

Alexander Langsdorf, Jr., Ph. D., Massachusetts Institute of Technology, 1937

F. P. Mooring, Ph. D., University of Wisconsin, 1951

CHARGED-PARTICLE REACTIONS

Permanent Staff

Thomas H. Braid, Ph. D., Edinburgh University, 1950

John R. Erskine, Ph. D., University of Notre Dame, 1960

Donald S. Gemmell, Ph. D., Australian National University, 1960

David C. Hess, Ph. D., University of Chicago, 1949

Robert E. Holland, Ph. D., University of Iowa, 1950

Linwood L. Lee, Jr., Ph. D., Yale University, 1955

Frank J. Lynch, B. S., University of Chicago, 1944

Luise Meyer-Schützmeister, Ph. D., Technical University of Berlin, 1943

John P. Schiffer,* Ph. D., Yale University, 1954

Ralph E. Segel, Ph. D., Johns Hopkins University, 1955

Jack R. Wallace, B. A., College of Wooster, 1942

J. L. Yntema, Ph. D., Free University of Amsterdam, 1952

Benjamin Zeidman, Ph. D., Washington University, 1957

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*Associate Director of Physics Division.

<u>Resident Research Associates</u>

Richard G. Allas, Ph. D., Washington University, 1961

Samuel I. Baker (RSA, thesis, Illinois Institute of Technology)

George B. Beard (Wayne State University), summer

David D. Borlin (RSA, summer, Washington University)

Richard S. Cox (RSA, thesis, Northwestern University)

Dietrich Dehnhard, Ph. D., University of Marburg/Lahn, 1964

Amnon Marinov, Ph. D., Hebrew University, 1962

Claus U. Mayer-Böricke, Ph. D., Heidelberg University, 1958

Lewis J. Milton (RSA, summer, University of Illinois)

Karl-Edvard Nystén, Ph. D., University of Helsinki, 1960

Rolf H. Siemssen, Ph. D., University of Hamburg, 1963

P. Paul Singh, Ph. D., University of British Columbia, 1959

Zeev Vager, Ph. D., Weizmann Institute of Science, 1952

Dieter von Ehrenstein, Ph. D., University of Heidelberg, 1960

GAMMA- AND BETA-RAY SPECTROSCOPY

<u>Permanent Staff</u>

Herbert H. Bolotin, Ph. D., Indiana University, 1955

S. B. Burson, Ph. D., University of Illinois, 1946

<u>Resident Research Associates</u>

Teymoor Gedayloo, M. S., University of Washington, 1960

William C. Johnston (RSA, thesis, Western Michigan University)

E. Brooks Shera, Ph. D., Western Reserve University, 1962

ATOMIC-BEAM STUDIES

Permanent Staff

William J. Childs, Ph. D., University of Michigan, 1956

John Dalman

Leonard S. Goodman, Ph. D., University of Chicago, 1952

MÖSSBAUER STUDIES

Permanent Staff

Juergen Heberle, Ph. D., Columbia University, 1955

Gilbert J. Perlow, Ph. D., University of Chicago, 1940

Richard S. Preston, Ph. D., Yale University, 1954

Stanley Ruby, B. A., Columbia University, 1947

Resident Research Associate

A. J. F. Boyle, Ph. D., Australian National University, 1957

VARIABLE-ENERGY CYCLOTRON

Permanent Staff

John J. Livingood, Ph. D., Princeton University, 1929

THEORETICAL PHYSICS

Permanent Staff

Fritz Coester, Ph. D., University of Zurich, 1944

Stanley Cohen, Ph. D., Cornell University, 1955

Hans Ekstein, Ph. D., University of Berlin, 1934

Melvin Hack, Ph. D., Princeton University, 1956

Morton Hamermesh, Ph. D., New York University, 1940

David R. Inglis, Ph. D., University of Michigan, 1931

Dieter Kurath, Ph. D., University of Chicago, 1951

Donald Lang, Ph. D., Australian National University, 1961

Robert D. Lawson, Ph. D., Stanford University, 1953

Malcolm H. Macfarlane, Ph. D., University of Rochester, 1959

James E. Monahan, Ph. D., St. Louis University, 1953

Murray Peshkin,* Ph. D., Cornell University, 1951

Norbert Rosenzweig, Ph. D., Cornell University, 1951

Resident Research Associates

Arnold Bodmer, Ph. D., Manchester University, 1955

Kurt Just (University of Arizona), summer

Harry J. Lipkin, Ph. D., Princeton University, 1950

Sudhir Pandya, Ph. D., University of Rochester, 1957

John K. Perring, Ph. D., Cambridge University, 1952

Bert Schroer (University of Pittsburgh), summer

Michitoshi Soga (Tokyo Institute of Technology), summer

John M. Soper, Ph. D., Trinity College of England, 1958

MASS SPECTROMETRY

Permanent Staff

Joseph Berkowitz, Ph. D., Harvard University, 1955

William A. Chupka, Ph. D., Harvard University, 1955

Manfred Kaminsky, Ph. D., University of Marburg, Germany, 1957

Henry E. Stanton, Ph. D., University of Chicago, 1944

Resident Research Associate

Kamel Refaey (RSA, thesis, Illinois Institute of Technology)

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*Associate Director of Physics Division.

RADIOFREQUENCY PLASMAS

Permanent Staff

Albert J. Hatch, M.S., University of Illinois, 1947

Resident Research Associate

Mazhar Hasan (Northern Illinois University), summer

ADMINISTRATIVE

Permanent Staff

Charles Eggler, B.S., Virginia Polytechnic Institute, 1944

Francis E. Throw, Ph.D., University of Michigan, 1940